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A SURVEY OF ANADROMOUS FISH LOSSES IN IRRIGATION DIVERSIONS FROM THE SACRAMENTO AND SAN JOAQUIN RIVERS[1]

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INTRODUCTION

In spite of the encroachment of modern civilization, California's Central Valley continues to embrace one of the most important king salmon (*Oncorhynchus tshawytscha*) spawning areas in the world. A sizable steelhead rainbow trout (*Salmo gairdneri gairdneri*) population also spawns annually in the Sacramento River system.

There are now more than 900 irrigation, industrial, and municipal water supply diversions above the Sacramento-San Joaquin River Delta from stream sections utilized by salmon, steelhead, and other anadromous fishes as migration routes to and from the sea. Most of these diversions are for irrigation. In the Delta there are many additional diversions. Along the Sacramento and San Joaquin rivers water enters the numerous canals and ditches primarily through pumping stations, which vary in size from single two-inch diameter pumps to installations of 10 pumps ranging in size from 42 to 100 inches in diameter. Water is diverted by gravity as well as by pumps into many ditches leading from the tributary streams. In addition, there are a large number of siphons, up to 60 inches in diameter, in the Delta. Very few of these diversions are screened to prevent fish losses, although trash grids at the headworks of many canals and on pump intakes prevent losses of adult fish.

Over the years, considerable experimentation on the development of mechanical and electric fish screens to prevent anadromous fishes from being destroyed in diversions has been carried out in California. Perhaps even more study has been directed towards determining the time of year when juvenile king salmon migrate from Central Valley streams to the sea. As early as 1899, fyke nets were fished for this purpose in the lower Sacramento River at the head of Georgiana Slough (Rutter, 1903). A 40-year period lapsed after this early fyke netting, only to be followed—from 1939 until the present—by a series of systematic netting operations, both by the California Department of Fish and Game and the United States Fish and Wildlife Service, to study fingerling salmon migrations.

[1] Submitted for publication January, 1959. This work was performed as part of Dingell-Johnson Project California F-7-R, "Sacramento-San Joaquin River Salmon and Steelhead Study," supported by federal aid to fish restoration funds.

[2] Both authors have transferred to Marine Resources Branch since this report was written.

Although considerable information has thus far been obtained on the migration times of juvenile Sacramento-San Joaquin River salmon and on how to prevent them from entering many types of ditches, particularly gravity diversions, only a comparatively moderate amount of study has been directed toward measuring actual fish losses at the various types of diversions, especially those utilizing pumps. Accordingly, in the spring of 1953 the California Department of Fish and Game initiated a survey of the multitude of unscreened diversions along the Sacramento and San Joaquin rivers and of the overall juvenile salmon and steelhead lossess occurring in them. While the task of measuring fish losses at each diversion would have been a monumental one and beyond the scope of the study, specific information was sought for typical diversions so that data obtained might be applied to other similar diversions. No attempt was made to study other than existing conditions, i.e., no experiments covering the effects of various theoretical diversion intake types on fish losses, etc., were conducted. Information on certain diversions for which an immediate evaluation of fish losses was essential, particularly on Butte Creek, a tributary to the Sacramento River, was also sought.

In 1953 and 1954 the diversion survey was centered along the Sacramento River between the cities of Redding and Sacramento. In 1955 the study was shifted to the San Joaquin River and into the Sacramento-San Joaquin River Delta. With an overall fish loss picture having been determined for the two principal rivers in the Central Valley,

FIGURE 1. One of the Redding Municipal Water Supply pumps, a 14-inch diameter turbine. Sacramento River near Redding, 1953. *Photograph by Don A. LaFaunce.*

work in 1956 and 1957 was concentrated on Butte Creek. This report summarizes irrigation diversion fish loss data obtained during the five irrigation seasons from 1953 through 1957, with the major emphasis on fingerling king salmon.

ACKNOWLEDGMENTS

Many people contributed to the irrigation diversion survey. The authors are particularly indebted to Leo Shapovalov, Assistant Chief of the Inland Fisheries Branch, for guidance during the study and for invaluable assistance in the final preparation of the manuscript for publication. Several other members of the California Department of Fish and Game also contributed vitally to the success of the program. Harry A. Hanson instigated the study and, along with Elton D. Bailey and Don A. LaFaunce, did much of the work during the first two years. Mr. Bailey also reviewed the manuscript and offered many helpful suggestions. John E. Riggs was in charge of field work during the last three years of the study.

STUDY PLAN

The original plan called for a listing of pumps along the Sacramento and San Joaquin Rivers, grouped according to factors thought to influence fish losses, such as size, type, depth and position of intake, etc. Next, the total seasonal loss of juvenile salmon and steelhead was to be determined for pumps selected as representative of each group. Other pumps would then be evaluated on the basis of results from those tested. It was also thought losses at the selected pumps could be weighted by the number of similar pumps in each group, to provide an estimate of the total seasonal losses in all pump diversions in the study area. The selected pumps from each group were to be drawn only from those which were thought to operate continuously during the irrigation season and which the survey had indicated could be sampled with fyke nets. A similar study, time permitting, was planned for Butte Creek.

This plan, however, was not strictly followed because some of the selected pumps which had operated continuously during the irrigation season while the pump classification surveys were being made did not operate or operated only intermittently during the season when the diversion sampling took place. In addition, limitations in the availability of both men and equipment reduced the area in which the studies could be effectively carried out, and made it impractical to sample all of the selected diversions along the entire Sacramento and San Joaquin Rivers above the Delta.

The study plan then of necessity was altered to include only an overall survey and a general evaluation of fish losses in the diversions, with specific fish loss data to be obtained for certain diversions under consideration for screening in the near future.

To determine this general picture of the losses through pumps, the areas between Princeton and Meridian on the Sacramento River and between Stockton and Patterson on the San Joaquin River were selected.

The numbers of fish passing through pumps were obtained by operating fyke nets in the canals behind pumps, and releasing marked fish to

determine net efficiencies. The sampling procedure consisted of setting one or more fyke nets in the canal as close to the discharge outlet of the pump as possible. The distance between the discharge outlet of the pump and the fyke net varied from a few feet to as much as one-half mile, but generally was less than 150 feet.

SAMPLING NETS

Riffle fyke nets of the type described by Hallock, Warner, and Fry (1952), and used by them to capture downstream migrant king salmon in the upper Sacramento River, were used to sample the discharge into

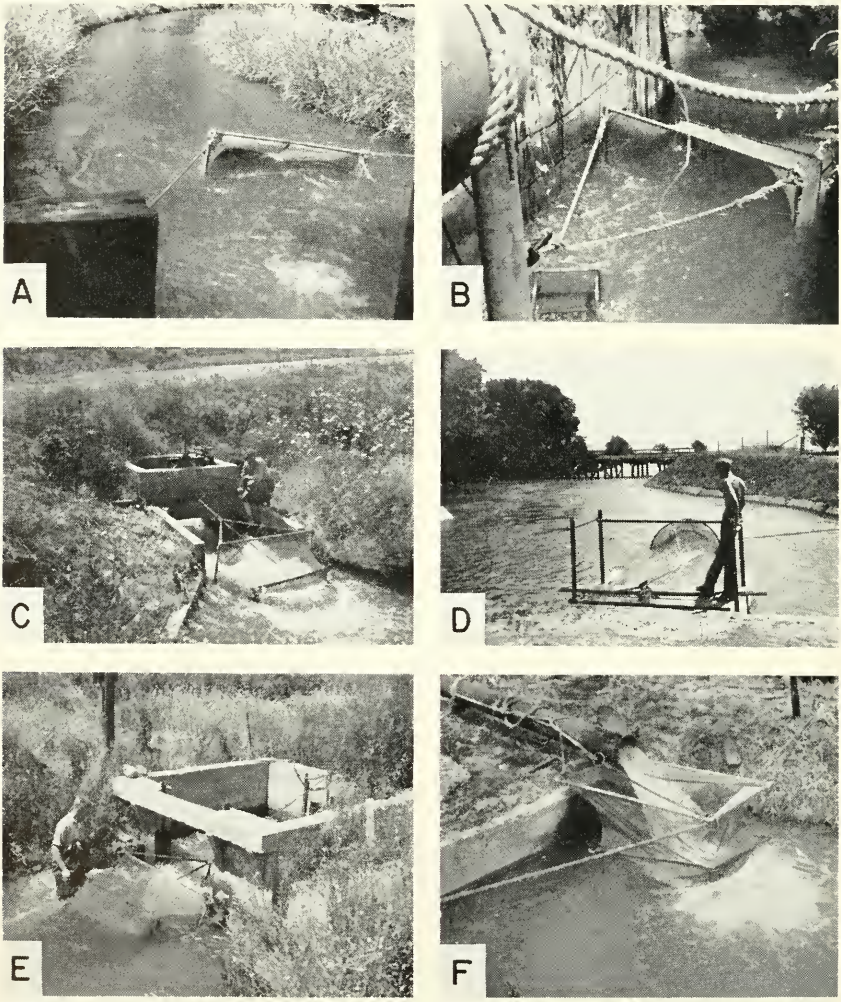

FIGURE 2. Fyke nets being fished in Sacramento River irrigation diversions during 1954, showing various methods of setting the nets. A, Hollis Sartain; B, Olive Percy Davis et al.; C, Wayne Hall; D, Sutter Mutual Water Company, Tisdale pumping plants No. 1 and No. 2; E, W. A. Larner; F, Tisdale Irrigation and Drainage Company. *Photographs A and B by Don A. LaFaunce; C, D, and F, by John E. Riggs; and E, by Elton D. Bailey.*

a number of the smaller ditches. These nets were made of one-half-inch stretched mesh cotton webbing hung on three rectangular metal frames. There was a 3-foot by 5-foot rectangular opening at the large end, and they were about nine feet long. A funnel of webbing tapered to a nine-inch square opening was installed inside the net at the second frame, 21 inches from the large open end. The pot of the net was formed by gathering together the webbing at the small open end and securing it with several turns of heavy twine.

Round fyke nets of slightly greater size were used to sample the discharge in the largest canals. These nets were also made of one-half-inch stretched mesh cotton webbing hung on three metal rings. They were 5 feet in diameter at the large open end and about 10 feet in length. A funnel of webbing, tapered to a round opening 11 inches in diameter, was installed inside the net at the second ring, 30 inches from the large open end. The pot of the net was formed in the manner described for the rectangular nets.

Simple bag nets of several shapes and sizes were used to sample the high velocity discharge from large pumps. These nets were made of one-half-inch stretched mesh cotton webbing, and had no funnels. One type was hung on a frame 4 feet square and had a bag 8 feet long. A second type was hung on a ring 3 feet in diameter, and also had a bag 8 feet long. The bag on the 3-foot circular net was later lengthened to about 10 feet, so that the pot could be moved to one side of the main discharge current to provide a resting place for the captured fish.

Near the end of the sampling period a round fyke net patterned after the one used by Schoeneman and Junge (1954) was made especially to sample the discharge from a 24-inch pump. This net consisted of a funnel of one-half-inch stretched mesh cotton webbing, a canvas pipe 8 feet long, and a live box of 2-inch cedar boards and hardware cloth (six meshes per inch). The funnel was 7 feet long. It tapered from 30 inches in diameter at the open end to 8 inches in diameter at the small end. The canvas pipe was eight inches in diameter. It had a metal ring sewn in at one end and a square metal frame at the other. The small end of the funnel and the round end of the pipe were sewn together. The live box was 18 inches wide, 24 inches high, and 36 inches long, with ends and framework of cedar, and was covered on the sides and bottom with hardware cloth. The box had a hinged lid, also covered with hardware cloth. One end of the live box had a rectangular opening at the top 7 inches wide by $7\frac{1}{2}$ inches deep, to receive the square end of the canvas pipe which slipped into a slot just inside the live box opening. The canvas pipe and the live box were fastened together by slipping the square end of the canvas pipe into the slot provided for it, closing the lid, and securing it with a wing nut. A baffle board was placed in the bottom of the box to provide a resting place for the small fish captured. It was usually necessary to place a weight in the bottom of the box to keep it upright. With the live box placed in still water, the fish were kept in essentially the same condition as when they came through the pump. By opening the lid and detaching the canvas pipe, the live box was easily carried to shore and emptied.

Another net of this type was used in 1955. It included a funnel 9 feet long, tapering from a 2-foot by 4-foot rectangular opening at the large

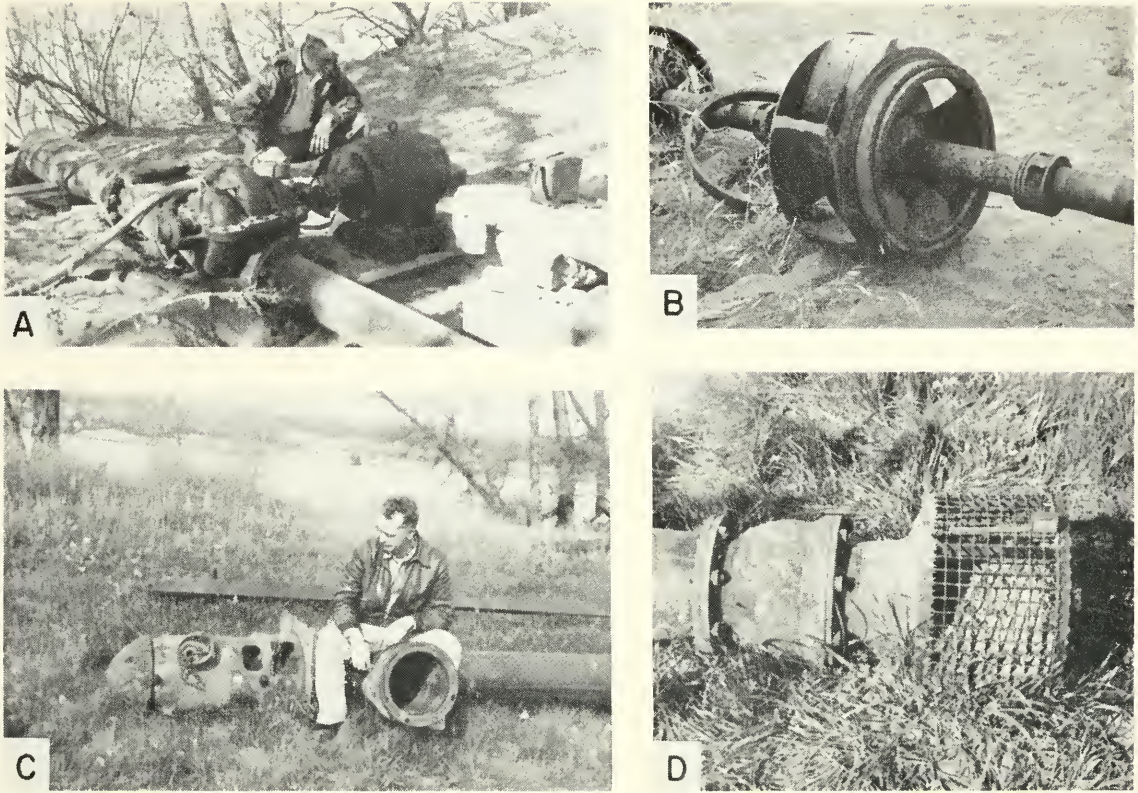

FIGURE 3. Typical pump types used in the Central Valley. A, Centrifugal pump, showing common installation method for single pumps; B, impeller from a centrifugal pump; C, screw-type pump; D, intake of a screw-type pump. *Photographs A, by Elton D. Bai'ey; B, by William F. Van Woert; C, by Don A. LaFaunce; and D, by John E. Riggs.*

end to 9 inches square at the small end. The canvas pipe was omitted, and the small end of the funnel slipped directly into a slot in the live box. The live box was made of aluminum perforated plate with $\frac{5}{32}$-inch round holes on $\frac{7}{32}$-inch centers.

PUMP TYPES

Practically all irrigation water is diverted from the Sacramento and San Joaquin rivers by pumps of one type or another.

The high-speed rotative units are of two main types: One utilizes an impeller, or runner, similar in shape to a ship's propeller, and is called a screw-type pump. The impeller is simply an inclined plane which when rotated slices under the water and lifts it. This type of pump has the advantage of being able to deliver more water than the second or centrifugal type of impeller, for any given size.

The centrifugal impeller pump operates differently from the screw type in that water is thrown out of it, into the discharge outlet, by centrifugal force. One advantage of the centrifugal pump is that it will continue to give fair service even after the impeller parts are considerably worn (of course, with some loss of efficiency). The drive shaft of a centrifugal pump may be mounted either vertically or horizontally, although horizontal mounting is the more common.

A few of the horizontal centrifugal pumps and most of the vertical ones are called turbines because they have special cases or housings which differ materially from the simple volute or spiral-shaped case. In turbines the case, or impeller housing, contains stationary vanes which help direct the water to the discharge pipe, or to the next stage in the event it is a multiple stage pump. These vanes mark the pump as a turbine, whether the impeller be of the centrifugal or screw type. In some instances, the runners or impellers of turbines are designed so they will have some of the properties of both the screw-type and centrifugal-type pumps. These are called combination or mixed flow pump impellers. They combine the high discharge capacity of the screw impeller with other desirable features found only in the centrifugal pump.

SACRAMENTO RIVER

Salmon Migration

Adult king salmon migrate into the upper Sacramento River system during all months of the year, but there are three periods each year when the migration is greatly intensified. These peaks in the migration represent three distinct runs of fish, while most of those moving upstream between the peaks are apparently either early or late segments of one of the three main runs: winter, spring, and fall (Hallock, Fry, and LaFaunce, 1957).

The movement of winter- and spring-run salmon is fairly continuous in the lower river, between early November and the last of May, but with considerable overlap, and it is difficult to distinguish clear-cut peaks in their migration. However, even though they move up the river at about the same time, these two groups of fish separate in the upper river as dictated by their spawning characteristics. Most of the winter-run fish spawn during May and June, in the upper portion of the main stem of the Sacramento River, between Anderson and Keswick Dam;

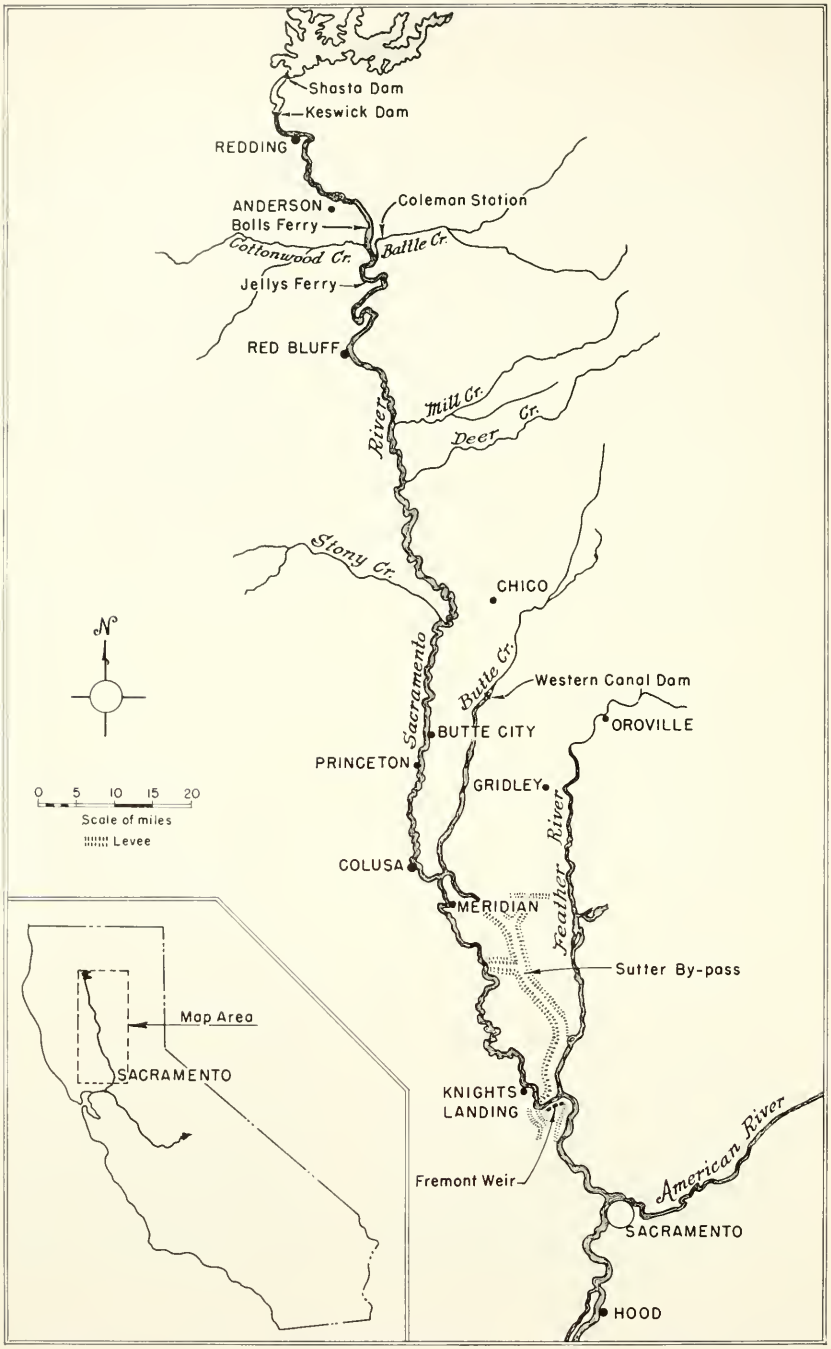

FIGURE 4. Map of the Sacramento River system, showing the areas where irrigation diversions were sampled.

however, in some years they also spawn in tributary streams. Spring-run fish spawn principally in late August, September, and early October. Spawning takes place primarily in the upper reaches of the Sacramento River above the City of Red Bluff, and in the higher reaches of the larger tributaries such as Butte, Deer, Mill, and Battle Creeks. The bulk of the fall run, which is larger in numbers than the other two combined, moves into the upper river between the middle of August and the early part of November. Most of the fall-run fish spawn between the middle of October and the latter part of December, with the greatest spawning activity taking place near the middle of November. Spawning takes place in the Sacramento River from a short distance below Chico to Keswick Dam, and also in the lower reaches of practically all suitable tributary streams.

The young of the Sacramento-San Joaquin king salmon either migrate to the ocean as soon as they reach the fingerling stage (when the yolk sac is absorbed and the fish can swim freely) or remain in the stream for about a year before going to sea. Between 80 and 90 percent of the young salmon go from fresh water to the ocean during their first year (Clark, 1929).

It is known that tremendous numbers of young salmon move down the Sacramento each winter and spring. Although there are no reliable estimates of the total numbers of migrants, partial figures are available for some years. For example, in the course of a marking experiment conducted by the California Department of Fish and Game in 1950, salmon were captured in the Sacramento River near Red Bluff, marked at the United States Fish and Wildlife Service's Coleman Fisheries Station on Battle Creek, and released in the Sacramento River at Jelly's Ferry. Marked fish were recaptured in sufficient quantity downstream at Red Bluff to provide a rough estimate of the total numbers passing the trapping site. According to figures based on recoveries following release of over 187,000 marked fish, close to 13,000,000 salmon moved downstream past Red Bluff between February 18 and March 10, 1950.

King salmon fry in the Sacramento River tend to move downstream at the time of seasonal increase in runoff. Salmon migration studies by the United States Fish and Wildlife Service in the Sacramento River at Balls Ferry, including 10 seasons of fyke netting between 1944 and 1953, show a measurable downstream movement between early October and the latter part of May in most years. The majority of the young salmon, however, migrate between early December and late April. The peak of the downstream movement varies from year to year; it may occur in late December, as in 1946, or even in late February, as in 1952. However, more often than not, two or even three peaks are evident between January and early March. Results of the 1944-1953 salmon migration studies at Balls Ferry are in agreement with the findings of studies made near the same location in 1899 (Rutter, 1903). Over 15,000 seaward migrants were handled between January 6 and April 25, 1899, and it was found that the height of the migration occurred between February 1st and 15th. Hanson, Smith, and Needham (1940) also noted a fall migration past Redding, finding a peak in mid-September of fish three to four inches long, thought to be salmon, which remained in the upper river (now blocked by Keswick and Shasta dams) over the summer.

Salmon migration studies also have been made in the lower Sacramento River. Fyke netting was carried out in the Sacramento River near Hood in 1899, 1940, 1941, 1947, and 1948. Findings were essentially the same in each of these years. Young king salmon were taken between mid-December and early June, with maximum numbers migrating during February and March, when as many as 80 percent of the total were taken.

Horizontal and Vertical Distribution of Downstream King Salmon Migrants

Between 1949 and 1953 tow net and push net operations by the United States Fish and Wildlife Service in the Sacramento River near Red Bluff revealed that during times of normal stream flows fingerling salmon migrate downstream at depths varying from the surface to four feet, moving in greatest numbers two to four feet under the surface. It was further demonstrated that the juvenile salmon migrate downstream fairly uniformly across the river but vary somewhat from midstream to the shores with changing water levels and velocities.

This is in accord with results of fyke netting operations carried on during the spring of 1950 by the California Department of Fish and Game in the Sacramento River just below Red Bluff. At that time 22 fyke nets were being fished side by side across the river over about half its width. Fingerlings were captured in all nets, with a few more fish usually being taken in the nets farthest from the shore.

During the 1954 netting operations in Sacramento River diversions it was discovered that during periods of high water and with flood conditions prevailing the fingerlings are spread throughout the river, and are to be found at considerable depths as well. In one instance near Colusa, fingerlings were being pumped in quantity into a canal when the pump intake was close to 20 feet under the river surface.

Irrigation Season

Records for the 10-year period, 1945-1954, show that the irrigation season along the Sacramento River between Sacramento and Redding extends from March to October (Figure 5). However, only 0.5 percent of the total seasonal volume used for irrigation is diverted in March and 8.4 percent in April. Seventy-six percent is diverted from May through August inclusive. An average of about 1,831,000 acre feet of water is diverted annually in this river section, which means that during the season an average of about 3,768 cubic feet of water per second leaves the river through the multitude of diversions during the entire eight-month season.

Fingerling Salmon Migration and the Irrigation Season

Individually the great majority of the pumping plants are small, and divert but a minor fraction of the Sacramento River flowing past their intakes. However, several of the larger ones do take enormous quantities of water, but usually late in the normal fingerling king salmon migration period. In 1954, the Glenn-Colusa Irrigation District diversion, which is the largest single diversion on the upper Sacramento, did not take water in February or March, but during April about 2.4 percent of the entire Sacramento River flowing past the intake was pumped onto the fields at this point. By May, 16 percent of the river's flow was

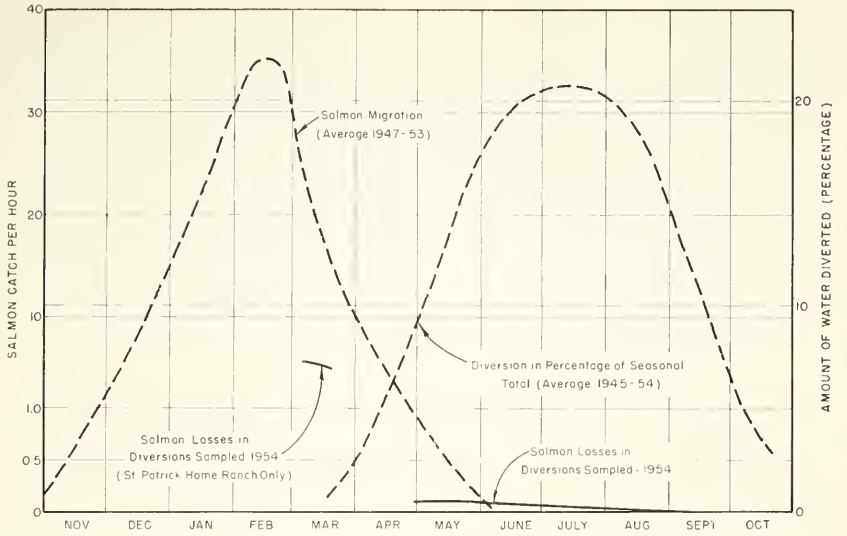

FIGURE 5. Comparison between times of the seaward migration of Sacramento River king salmon fingerlings, their losses in irrigation diversions, and the diversion of water for irrigation. The salmon migration was determined by fyke netting in the Sacramento River at Balls Ferry. Salmon losses were determined by fyke netting in irrigation diversions from the Sacramento River between Butte City and Knights Landing. The average diversion of irrigation water in percentage of the seasonal total includes data for the entire river between Sacramento and Redding.

being taken by this one diversion. Farther downstream near Meridian, the Sutter Mutual Water Company's large diversion took only 0.6 percent of the Sacramento River flowing past their pumps during April. However, during May, 10 percent of the river's flow was diverted.

A comparison between times of the annual seaward migration of juvenile salmon and the combined acre feet of water diverted by all pumps along the Sacramento River between Redding and Sacramento reveals that during most years the majority of the fingerlings have moved out of the upper river before the irrigation season gets into full swing (Figure 5). However, the migration tapers off through the spring and early summer, so some losses are to be expected each year during most of the summer months, particularly at the larger diversions. This is what occurred in 1954.

The one pump found to be operating in March, 1954, illustrated the potential danger of pumping, even during near-flood flows in the river, when fingerlings are migrating, since considerable losses of salmon occurred (Figure 5). Further reference to this pump, St. Patrick Home Ranch, appears in the section, "Diversions Sampled and Fish Losses."

The percentage of stream flow which is being diverted is perhaps of equal significance with the time when water is being diverted in determining salmon losses during the migration period. In 1954, less than 1 percent of the Sacramento River between Redding and Knights Landing was diverted in March, and less than 5 percent in April. However, by May, after most of the salmon had already migrated out of the upper river and into the Delta, about 25 percent of the river flow was diverted from this stream section.

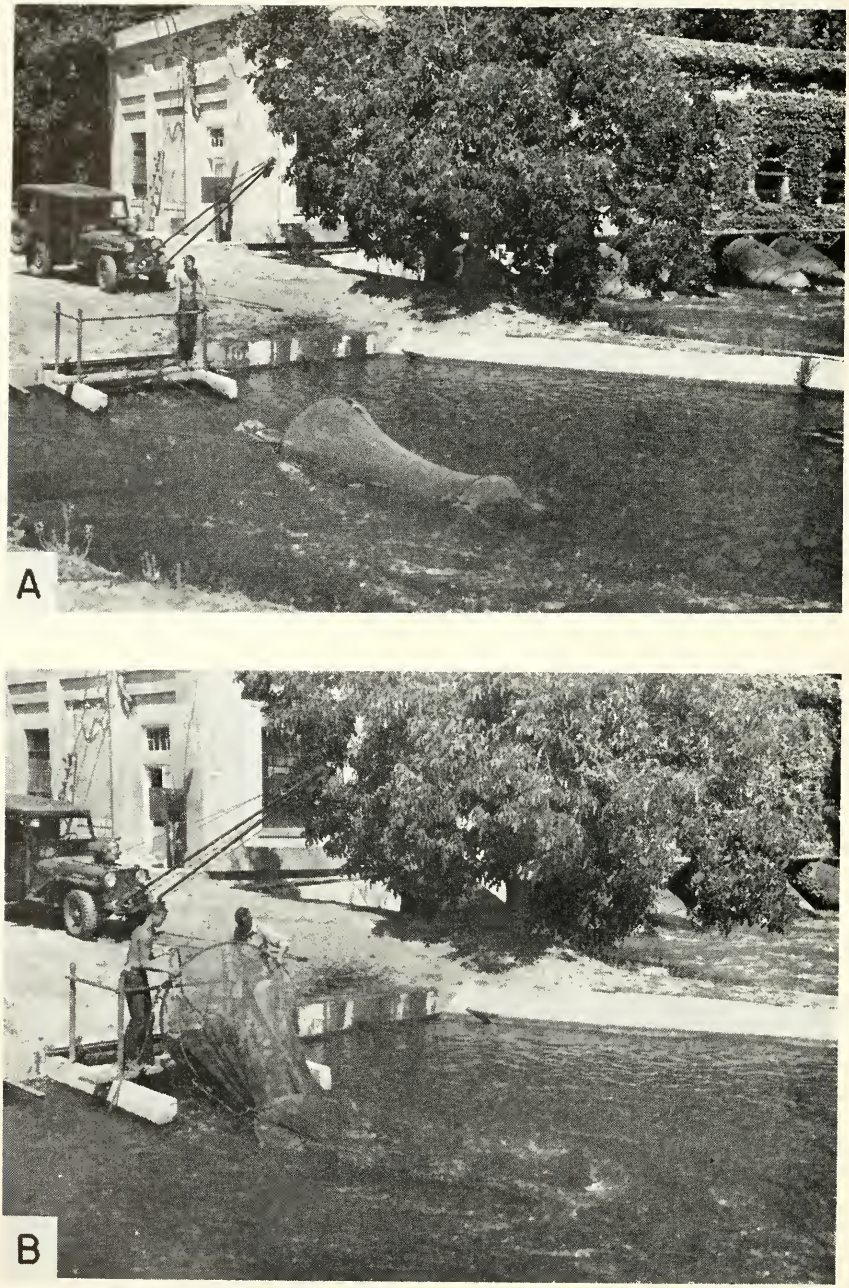

FIGURE 6. Fyke netting in the Sutter Mutual Water Company's Tisdale plants No. 1 and No. 2, Sacramento River, 1954. A, netting the discharge from two 48-inch diameter pumps; the discharge pipes from six 42-inch diameter pumps appear in the right background; B, putting net back in the canal after removing catch and cleaning; the jeep winch and hoist were used to remove the net from the water. *Photographs by John E. Riggs.*

Diversions Sampled and Fish Losses

In 1953 there were 335 separate diversions, utilizing a combined total of 448 pumps, along the Sacramento River between Redding and Sacramento, with the centrifugal-type pumps outnumbering the screw-type about 2 to 1. These pumps varied in size between 1¼ and 100 inches in diameter, with about 80 percent being from 6 to 24 inches in diameter. Eleven percent were larger than 24 inches in diameter. Preponderantly the diversions are single and double pump installations supplying water to limited acreages. However, along the river section between Knights Landing and Butte City, where the 1954 diversion sampling was conducted, there are also several larger pumping plants, including those of the Sutter Mutual Water Company (Tisdale plants No. 1 and No. 2), which utilize seven pumps ranging in size from 42 to 48 inches in diameter; Reclamation District No. 1,004, with three pumps from 30 to 50 inches in diameter; Provident Irrigation District, with five pumps from 24 to 42 inches in diameter; and the giant Glenn-Colusa Irrigation District diversion, with 10 pumps from 28 to 100 inches in diameter.

During 1953, initial surveys were made of 371 pumps, representing 294 separate diversions from the 246-mile section of the Sacramento River between Redding and Sacramento. At each pump site, information was obtained on factors believed to influence fish losses, such as size and type of pump, depth of intake, distance between intake and river bank, angle at which the intake pipe entered the water, velocity of flow past the intake, and size and type of intake screen if present. In each case, it was also determined whether or not the diversion could be adequately sampled for fish losses.

Pump intakes were located by probing with a three-quarter-inch by 12-foot aluminum pipe, with 6-inch graduations. This pipe was used to measure the depth of the intake and the distance between the intake and the river bank. The angle at which the intake pipe entered the water was estimated. Velocity of flow past the intake was measured with a Leitz current meter. Since the water was usually murky, information on the size and type of intake grids or screens was usually obtained from the owner or ranch foreman. This information applied only to the time that the intake was installed or last repaired, and therefore the condition of the screen at the time the survey was made was generally unknown. Data gathered on each pump were recorded on a "Unisort" edge-punched card to facilitate grouping and sample selection.

The Anderson-Cottonwood Irrigation District diversion at Redding was the only gravity flow diversion found along the upper Sacramento River; the remainder divert water by pumping.

A total of 23 diversions was sampled intermittently for fish losses during the 1953 irrigation season, with the greatest effort being expended during midseason. No diversion was found to be taking fingerling salmon or steelhead in serious quantities (Table 1).

In 1954, fyke nets were fished in nine selected diversions in the vicinity of Colusa, all with pumps from 14 to 50 inches in diameter, from late April through September. Fyke nets were also fished in other diversions for varying lengths of time (Table 2). Although some losses occurred during the entire irrigation season, particularly during the early part, the findings were essentially the same as in 1953, in that fish

TABLE 1

Diversions Sampled on the Sacramento River in 1953

Diversion	Location (mile and bank above Sacramento)	Number and size (diameter in inches) of pumps	Date	Hours of fyke netting	Number of juvenile salmon captured	Remarks
Anderson-Cottonwood Irrigation District	240.5 L	4–16	April 6–Aug. 20	134	136	All of the king salmon were captured during the period April 6-16, 1953. Combined catch of two nets.
Olive Percy Davis, et al.	78.8 R	1–24	July 27–Aug. 13	128	26	Pump broke down during night of July 27; time unknown.
Reclamation District No. 1004	112.1 L	2–30 1–50	June 3–18	94	1	
R. Pheiffer	155.7 R	1–2½	May 28–30	45		
V. G. Strain	150.8 R	1–12 1–16	June 16–17	26		
Provident Irrigation District	124.2 R	2–24 1–36 2–42	June 23–25	49		
Princeton-Codora Glenn Irrigation District	123.9 R	5–24	June 2–4	42		Combined catch of two nets.
Princeton-Codora Glenn Irrigation District	112.4 R	3–24	June 3–9	140		
Hollis Sartain	99.2 L	1–20	July 29–30	20		
Azro N. Lewis	95.6 L	1–12 1–20	Aug. 10–13	69		
Roger Wilbur	95.25 L	1–12 1–18	July 28–30	44		Not enough velocity to make a good set. Periodic water changing among ditches.
Roger Wilbur	87.4 R	1–10	July 27–28	8		Entire discharge sampled.
Wayne Hall	81.8 L	1–16	July 14–17	70		
Meridian Farms Water Company No. 1 and No. 2	80.0 L	1–10 1–20 1–24	July 15–17	48		
Olive Percy Davis, et al.	78.75 R	1–16 2–12	Aug. 10–13	64		
Robert Chesney	76.15 L	1–10	July 14–17	67		These pumps both discharge into the same basin; both pumps were operating during sampling.
J. H. Yates Estate	76.1 L	1–10				

TABLE 1

Diversions Sampled on the Sacramento River in 1953—Continued

Diversion	Location (mile and bank above Sacramento)	Number and size (diameter in inches) of pumps	Date	Hours of fyke netting	Number of juvenile salmon captured	Remarks
Meridian Farms Water Company No. 3	71.8 L	1 18	July 15 17	46		
Meridian Farms Water Company No. 4	71.1 L	1 24	Aug. 10–13	65		An estimated 60-70 dead salmonids (young and adults) observed in ditch August 10-12, 1953.
Faxon, Morton and P. Andreotti	69.2 R	1 10 2–16	July 27–30	34		
J. L. Browning	69.0 R	1 14 1–22	July 28	6		Only the 14-inch pump operated during sampling.
Newhall Land and Farming Company	67.5 L	1–12 2–24	July 11 17	64		
Natomas Central Mutual Water Company	16.0 L	1 24 2–32 2–38	Aug. 18–19	24		

losses at individual pumps were quite small. For example, the greatest seasonal loss encountered in 1954 consisted of 2,116 fingerling salmon and 110 yearling steelhead in the Olive Percy Davis diversion, with a 24-inch centrifugal pump. These are weighted figures, based on efficiency tests of the fyke nets fished in the canal behind the pumps, and represent the entire catch for the season. One pump was found to be operating unseasonally early, in March, 1954. This was a 20-inch centrifugal pump owned by the St. Patrick Home Ranch located between Princeton and Colusa. Fyke nets were fished in this diversion for eight days during the first half of March and over 1,200 fingerling salmon were captured. In addition, pieces of two adult salmon and one adult steelhead were recovered. This diversion was sampled again for three days during July, and no salmon or steelhead were taken.

There are indications that considerable damage could be done to the salmon and steelhead populations through losses of adults at pump intakes which do not have a trash grid or screen. A 24-inch centrifugal pump (Meridian Number 4) was sampled for three days in August, 1953. During this short period, 22 adult king salmon and 2 adult steelhead were captured in fyke nets. All were dead. In addition, between 60 and 70 dead adult salmon, which had either entered the canal before sampling began or were not captured in the fyke nets, were found floating in the ditch. Between the 1953 and 1954 irrigation seasons, a two-inch bar grill was placed over the pump intake by the irrigation company. In September, 1954, this diversion was examined again and no dead salmon were found in the canal.

TABLE 2

Diversions Sampled on the Sacramento River in 1954

Diversion	Location (mile and bank above Sacramento)	Number and size (diameter in inches) of pump	Date	Hours of fyke netting	Number of juvenile salmon captured	Fyke net efficiency (Percent)	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency and hours of fyke netting	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency and total possible hours of fyke netting during periods when salmon were captured
Olive Percy Davis, et al.	78.8 R	1-24	May 2-Sept. 11[1]	1,277	297	48.5	612	2,116
Meridian Farms Water Company No. 1 and No. 2	80.0 L	1-10 1-20 1-24	April 25-Sept. 18[2]	1,399	26	40.9	63	148
Reclamation District No. 1004	112.1 L	2-30 1-50	May 2-8	38	3			
Thousand Acre Ranch, H. W. Keller	106.0 R	1-14	April 25-May 29	290	4	Low velocity 95 percent of flow strained		
Charles W. Welch	103.7 R 103.8 R	1-16 1-14	April 25-May 8	115	2			
Nettie George and Ella Packer	102.8 R	2-12 1-20	May 9-29	167	1			
St. Patrick Home Ranch	101.1 R	1-20	Feb. 28-July 24	387	1,266	100.0 percent of flow strained		
Mayfair Packing Company	88.7 L	1-14	Oct. 3-9	8				
Howell Davis	86.2 R	1-18	July 4-10	44				
Wayne Hall	81.8 L	1-16	June 6-Sept. 25	1,242		66.0		

Olive Percy Davis, et al.	78.75 R	2-12 1-16	May 2-June 12	116	1	
J. H. Yates Estate	76.1 L	1-10	May 9-15	16		
Meridian Farms Water Company No. 3	74.8 L	1-18	April 25-Sept. 18	1,208	2	17.3
Meridian Farms Water Company No. 4	71.1 L	1-24	April 25-May 22	209	2	
Hoffman, Beckley, Ritchie, Poundstone and Andreotti	70.4 R	1-16 1-20	April 18-Sept 4	811	3	70.0 percent of flow strained
Faxon, Morton and P. Andreotti	69.2 R	2-16	June 13-Sept. 4	686		75.0 percent flow strained
Newhall Land and Farming Company	67.5 L	1-12 2-24	April 25-May 8	156		
Tisdale Irrigation and Drainage Company	67.1 L	1-16 1-22	April 25-June 12	446		Medium velocity 50 percent of flow strained
Tisdale Irrigation and Drainage Company	64.4 L	1-8 1-12	May 28-Sept. 18	113		100.0 percent of flow strained
Sutter Mutual Water Company	63.75 L	2-48	May 23-Sept. 18	479	37	
W. A. Larner	60.4 L	1-14 1-16	May 16-Oct. 2	914	2	13.8
Sacramento River Ranch	22.5 R	1-24	May 19-22	38	7	

[1] No estimate May 30-June 5.
[2] No estimate May 30-June 19 and June 27-September 18.

A summary of the individual diversions sampled with fyke nets during 1953 and 1954, together with the catches of all species, appears in the Appendix.

The only diversions in which fyke nets were fished along the upper Sacramento River during 1955 were the Meridian Farms Water Company Number 1 and Number 2 and the L. W. Seaver ditches. The pumping plant for the former is located near the City of Meridian and the one for the latter near Princeton. Nets were fished during the last week in March and the first week in April in the Meridian diversion and for one week only, in mid-March, in the Princeton diversion. Results, although meager, further substantiated findings from the 1954 work done on the Sacramento River in this same area.

FIGURE 7. Method used to clean the fyke nets. The net has been suspended from a hoist on the front of the jeep and the debris is being washed away with a 1½-inch diameter portable pump. The men beside the jeep are sorting the catch. Meridian Farms Water Company diversions No. 1 and No. 2, Sacramento River, 1954. *Photograph by Elton D. Bailey.*

Previous Diversion Sampling

In several instances, previous diversion sampling by the Department of Fish and Game along the upper Sacramento River and some of its tributaries resulted in similar experiences, since the young fish had migrated downstream before the irrigation season got under way. For example, between May 1 and June 9, 1943, fyke nets were fished in the Feather River near Oroville and in the Sutter Butte Canal Company and Western Canal Company diversions, which take water from the Feather River near Oroville. Results of the study were summarized by the statement that, "the movement of salmon was evidently early,

and most of them had moved out of the river by the time the ditches began taking water. Results obtained cannot therefore be considered significant."

However, fyke nets were also fished in the Feather River near Gridley from January 23 to May 31, 1944, and from January 13 to May 28, 1955, and it was found in each instance that the heaviest downstream movement of juvenile king salmon occurred during March and April. The Western Canal Company ditch opened in mid-April in 1944 and took very few salmon that year. The Sutter Butte Canal Company diversion opened early in April during 1944, and moderate numbers of salmon were taken in this canal between mid-April and the end of May.

Nets were also fished in the Sacramento River near Chico between May 1 and June 9, 1943, and in the Glenn-Colusa Canal, which diverts water from the Sacramento River at a nearby point. Practically no young salmon were taken, and it was concluded, as in the case of the Feather River, that most of the fish had migrated past this area before the netting was started. However, nets operated between April 18 and August 20, 1929, in the same diversion took large numbers of game fish, including salmon and steelhead. Substantial numbers of salmon were being lost in this canal even in late June, 1929.

Conclusions (Sacramento River)

On the basis of the 1953 and 1954 Sacramento River studies, appreciable losses of salmon in irrigation diversions now occur at few places on the river itself above Meridian. Individually, most of the small irrigation diversions do not destroy many young salmon and steelhead. Collectively, however, they do take considerable numbers. The largest diversion, that of the Glenn-Colusa Irrigation District, was not sampled adequately, nor was the large Anderson-Cottonwood Irrigation District gravity diversion at Redding. In view of the migration time of fingerling salmon, which results in the bulk of the fish moving out of the upper river and reaching the delta by late March, and an irrigation season which does not get into full swing until late April and early May, the small losses encountered in the diversions are not surprising. However, sampling has shown that the unscreened diversions do take fish at times when the pumps are in operation while fish are migrating, even under near flood conditions. A change in agricultural practices, resulting in an earlier irrigation season, or the installation of year-round diversion canals for the transportation of water to other areas of the State, could prove disastrous to the Sacramento River salmon resources unless adequate screens were provided.

Although losses at pumping plants along the upper Sacramento River were found to be very small during the spring of 1953 and 1954, it should not be concluded that losses of the same low magnitude occur in diversions from tributary streams. On the contrary, losses are known to be considerable in diversions from many tributaries. One of the leading factors contributing to this situation is a generally later spawning (and later downstream migration of young) of fall-run salmon in tributaries than in the Sacramento River. This situation results from low flows in tributary streams early in the fall, which make the spawning beds inaccessible until the first rains of winter arrive. Another factor contributing to large losses in some tributary stream diversions is the removal

of an increasing percentage of the stream flow as the season progresses, until the fish have no place to migrate except down the diversions.

SAN JOAQUIN RIVER

Salmon Migration

The annual migration of adult king salmon into the San Joaquin River system has consisted almost entirely of fall-run fish in recent years. Remnants of former large spring runs still persist in the Merced River, and to a much lesser degree in some of the other tributaries. Since the annihilation, by 1949, of salmon stocks which once spawned in the upper San Joaquin River, as a result of the lack of water releases from Friant Dam, the once important San Joaquin has served only as a passageway for salmon destined to spawn on riffles of tributary streams, including the Merced, Tuolumne, Stanislaus, Mokelumne, and Cosumnes Rivers.

The former San Joaquin River spring run, which included 56,000 salmon in 1945 and was valued at almost one million dollars annually, migrated past the mouth of the Merced between the middle of April and the middle of June, and usually peaked there in the first half of May. At Mendota, some 60 miles farther upstream, the adult run peaked during the early part of June. Spawning then took place in September and

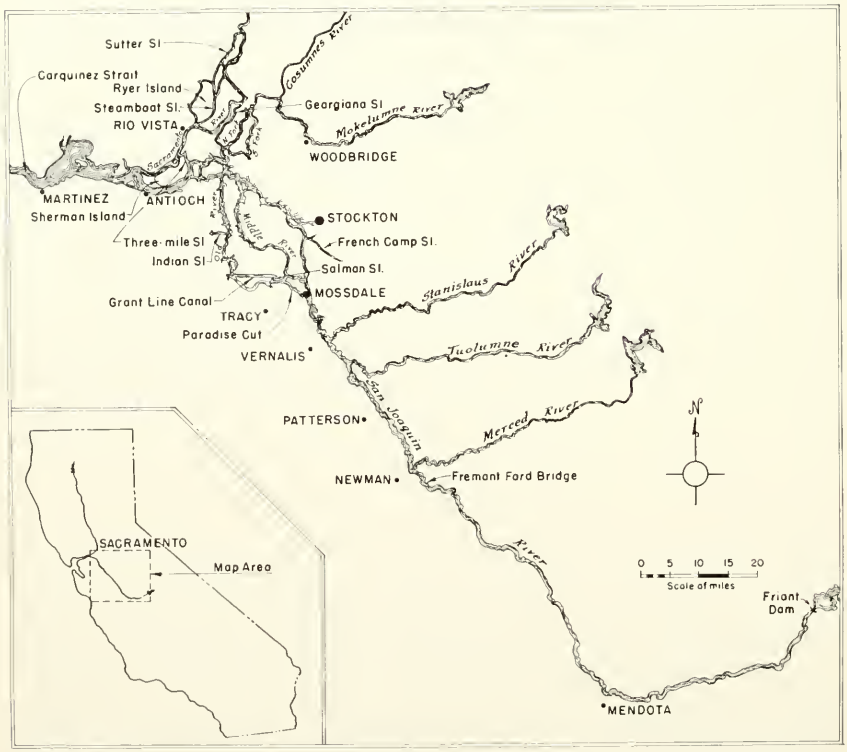

FIGURE 8. Map of the San Joaquin River system and the Sacramento-San Joaquin River Delta, showing the areas where irrigation diversions were sampled.

early October in the San Joaquin River near Friant. In 1948 the Department of Fish and Game trapped 1,915 adult king salmon and hauled them to a canal through which they bypassed a dry section of the San Joaquin and reached the Friant Dam area safely. This was the last of this spring run.

The present fall run usually occurs a few weeks later than the Sacramento River fall run. There is also considerable variation in the time when these fish enter the tributaries. The Cosumnes and Merced Rivers have notoriously late runs, perhaps due in most years to low early flows, so that sometimes fish do not spawn in them until the middle of November. However, in the other tributaries the runs usually start in early October and continue through the middle of December, with a peak being reached some time in November.

The seaward migration of juvenile salmon in the San Joaquin River system occurs during the period of major seasonal runoff, as it does in the Sacramento. This was noted especially in studies made in 1940, prior to the storage of water at Friant Dam. However, while the storage of water behind Shasta Dam has had very little measurable effect upon the time pattern of juvenile salmon migrations in the Sacramento River, the storage of water at Friant Dam has brought about a considerable change in San Joaquin River fish migrations.

Fyke netting by the Department of Fish and Game in the San Joaquin River near Mendota between 1944 and 1949 showed that the majority of the fish then passed Mendota between late January and early June. In 1944 the migration of juvenile salmon was heavy at Mendota from January 27 through March and reached a peak in mid-February. Farther downstream, fyke netting at Mossdale in 1939 and 1940 demonstrated a measurable seaward movement of fingerling salmon between January and mid-June, with the greatest numbers descending during February and March. The highest percentage of the total number of migrants taken during any one month was 61 percent, during February, 1940.

The elimination of San Joaquin River flood flows as a result of water storage at Friant Dam considerably altered the juvenile salmon migration pattern. In 1948, at Mendota, there was a fairly steady downstream migration between February and June, but the peak was not reached until April. In 1949 the seaward migration was again measurable at Mendota between February and June, with peaks in early March and again in mid-May.

Juvenile salmon passing Mendota, at least in the decade prior to 1949, were for all practical purposes the progeny of spring-run adults only, since very few fall-run fish spawned in the upper San Joaquin. In 1948 and 1949 the last of the downstream migrants from the upper San Joaquin reached Mendota, only to be destroyed in irrigation diversions nearby. Only enough water was released from Friant Dam to fill the needs of agriculture, thus leaving a dry streambed, except for return irrigation water, from a few miles below Mendota to the mouth of the Merced, a distance of some 60 miles.

Fyke netting in the Delta in 1948 and 1949, then, for the first time did not include catches of fingerlings from the upper San Joaquin. All fingerlings were from spawning beds of tributary streams and were primarily the progeny of fall-run adults. This condition has existed

until the present time, i.e., the tributary streams from the Merced River to the Cosumnes now support the entire San Joaquin River salmon runs.

In 1948 and 1949 the San Joaquin River system seaward migrants did not reach the Delta near Stockton until the first week in April. This was six weeks after those from the Sacramento River drainage began entering the Delta waters near Hood. During 1949, salmon fingerlings moved seaward through the lower San Joaquin and into the Delta while the stream flow was actually receding, and it continued to recede during the migration period. In 1955 the peak of the downstream migration near Newman occurred between mid-March and mid-April. Thus, with the elimination of the early spawning spring run which formerly used the gravels above Mendota, and the storage of water at Friant, the juvenile salmon migration time pattern in the San Joaquin has changed considerably. During years of normal runoff, it formerly peaked near Stockton in February and it now peaks there around the last of March.

Irrigation Season

Records for the 10-year period (1946-55) show the irrigation season along the San Joaquin River between Stockton and the mouth of the Merced River to be principally between March and October, with some water diverted in February and November (Figure 9). Upstream, at Mendota, water is usually diverted during all months of the year. The monthly diversion of water in percentage of the seasonal total indicates that—between Stockton and the Merced River—5.8 percent is diverted in March, 14 percent in April, and 14 percent in May. About 67 percent is diverted from May through August, inclusive. On an average, about

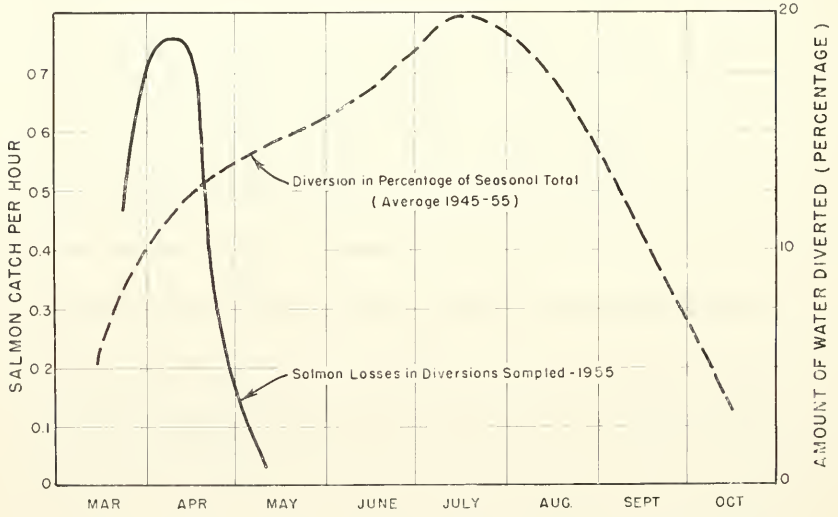

FIGURE 9. Comparison between times of San Joaquin River king salmon fingerling losses in irrigation diversions and the diversion of water for irrigation. Salmon losses were determined by fyke netting in irrigation diversions from the San Joaquin River between Patterson and Stockton (Old River). The average diversion of irrigation water in percentage of the seasonal total includes data for the entire river between Stockton and Newman (Fremont Ford.)

127,000 acre-feet of water are diverted annually in this river section, which means that during the eight principal months of the irrigation season an average of approximately 261 cubic feet of water per second leaves the river through the many diversions.

Fingerling Salmon Migration and the Irrigation Season

In comparison with Sacramento River diversions, those along the San Joaquin divert a much greater percentage of the river flow during the time when salmon fingerlings are migrating. For example, in 1955, Patterson Water Company diverted 17 percent of the entire flow of the San Joaquin River at its diversion intake during March, and by May was taking 20 percent of the flow. Farther downstream, at the Banta-Carbona Irrigation District intake, 4 percent of the river flow was diverted in March and 17 percent in April. A comparison between time of annual seaward migration of juvenile salmon, as determined by fyke net catches in irrigation diversions, and time of diversion of the combined volume of water diverted from the San Joaquin River in 1955 by all pumps between Stockton and the Merced River, shows that a much greater overall percentage of the seasonal irrigation water was pumped during the time fingerling salmon were migrating than on the upper Sacramento (Figure 9). Under these conditions, considerable fish losses were expected in the diversions sampled, and that is what happened during the 1955 irrigation season. The fish losses along the San Joaquin result not only because the irrigation season coincides with the juvenile salmon migration, but also because a large percentage of the entire San Joaquin flow is diverted early in the irrigation season, during the salmon migration period. In 1955 all pumps between Stockton and Patterson diverted about 20 percent of the entire San Joaquin flow in March and 40 percent in April.

Diversions Sampled and Fish Losses

In 1955 there were 113 separate diversions, utilizing 159 pumps, along the San Joaquin River between Stockton and the mouth of the Merced River. These diversions do not include those from French Camp Slough and Old River. The pumps varied in size from 2 to 36 inches in diameter, with about 85 percent being from 6 to 24 inches in diameter. As on the Sacramento River, the majority of the diversions are headed by single and double pump installations, with a few larger pumping plants which supply water to vast irrigation districts. The four largest water users include the Banta-Carbona Irrigation District, which utilizes 10 pumps ranging in size from 10 to 36 inches in diameter; West Stanislaus Irrigation District, with eight pumps from 12 to 26 inches (six of which are 26-inch pumps); Patterson Water Company, with seven pumps from 14 to 36 inches; and El Solyo Water Company, with a battery of four pumps from 10 to 18 inches in diameter.

Rather than to spend a season surveying the more than 100 diversions along the upper San Joaquin, as had been done in 1953 on the Sacramento, it was decided to forego this work on the San Joaquin and sample several of the larger typical pumping stations thoroughly during the entire 1955 season. This was done for the sake of expediency and to obtain a general picture of fish losses sooner. Previous work at several diversions in this area furnished some information and made this approach possible.

TABLE 3

Diversions Sampled on the San Joaquin River in 1955

Diversion	Location (mile and bank above mouth)	Number and size (diameter in inches) of pump	Date	Hours of fyke netting	Number of juvenile salmon captured	Fyke net efficiency (percent)	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency and total possible hours of fyke netting during periods when salmon were captured
Banta-Carbona Irrigation District	67.5 L	2-10 2-16 2-20 3-24 1-36	Mar. 20-May 28[1]	504	386	6.4	6,024	19,748
El Solyo Water Company	82.0 L	1-10 3-18	Mar. 20-June 11[2]	428	105	4.7	2,234	9,494
Patterson Water Company	104.4 L	1-14 2-18 3-30 1-36	Mar. 20-May 28[3]	536	21	2.4	875	2,157

[1] No estimate May 15-28.
[2] No estimate April 24-June 11.
[3] No estimate March 20-26, April 17-23, and May 8-28.

In the spring of 1955, then, practically all of the diversion sampling was done on the San Joaquin River and in the Sacramento-San Joaquin River Delta. Pump diversions in which nets were fished along the San Joaquin included the Banta-Carbona Irrigation District and the El Solyo and Patterson Water Companies, located along a 43-mile section of the San Joaquin River between Stockton and Patterson. The large West Stanislaus Irrigation District diversion above Stockton was not sampled, but previous studies had shown this pumping plant to be an important salmon destroyer. All of the diversions sampled in 1955 on the San Joaquin River appear to be destroying more fingerling salmon than any of those sampled during the 1953, 1954, or 1955 seasons along the upper Sacramento River (Table 3). Of those diversions on the San Joaquin which were successfully studied, the Banta-Carbona Irrigation District pumping plant appears to be one of the greatest destroyers of young salmon. This irrigation district includes 17,000 acres of land. The diversion point is located on the west bank of the San Joaquin some 10 miles east of Tracy. The water flows by gravity about one mile to the headworks, where there are 10 pumps ranging in size from 10 to 36 inches in diameter. The average monthly flow through these pumps during April, May, and June for the five-year period 1948 through 1952 was slightly over 125 cubic feet per second. Juvenile salmon migrating down the San Joaquin River past the intake originate in the Merced, Tuolumne, and Stanislaus Rivers, all of which flow into the

FIGURE 10. Two of the large irrigation diversions sampled along the San Joaquin River in 1955. A, Patterson Water Company pumping plant; B, Banta-Carbona Irrigation District pumping plant No. 1; C, Patterson Water Company canal, view toward the pumping plant; D, Banta-Carbona Irrigation District canal near pumping plant No. 2. *Photographs A, C, and D by John E. Riggs; and B, by William F. Van Woert.*

San Joaquin farther upstream. The studies showed that close to 20,000 juvenile salmon were destroyed in this one diversion during a two-month period between the middle of March and the middle of May, 1955.

During a one-month period of testing, between the middle of March and the middle of April, 1955, the El Solyo Water Company diversion, situated on the west bank of the San Joaquin River near Vernalis, took over 9,000 fingerling salmon. This diversion, which at the headworks includes four pumps ranging in size from 10 to 18 inches, has a normal average pumping rate of about 35 cubic feet per second during the salmon migration period. The intake is located above the mouth of the Stanislaus River, so that downstream migrants at that point originate in the Merced and Tuolumne rivers only. Percentage-wise, this diversion may be a greater destroyer of young salmon than the Banta-Carbona, since it draws from the migrants of one less river.

The same reasoning might also be applied to the results of studies made at the Patterson Water Company diversion. This company diverts water from the west bank of the San Joaquin River near Patterson, to provide for an irrigation district which includes 15,000 acres of land. At the headworks there are seven pumps, ranging in size from 14 to 36 inches in diameter. During the salmon migration period, flow through the pumps averages close to 110 cubic feet per second. Studies showed that between the middle of March and the early part of May more than 2,000 fingerling salmon were lost in this canal. However, although the number of fish destroyed was small, these fish were important, for this diversion draws on migrants only from the Merced River, and the run of adult salmon into the Merced the previous spring and fall was probably less than 1,000 fish.

A summary of the individual diversions sampled with fyke nets during 1955, along with catches of all species, appears in the Appendix.

Conclusions (San Joaquin River)

The 1955 studies on the San Joaquin River show that all of the large diversions sampled between Stockton and Patterson are destroying appreciable numbers of salmon fry. This is not surprising, since between 20 and 40 percent of the entire river flow is pumped into irrigation canals during the period when salmon are migrating downstream in this river section.

SACRAMENTO-SAN JOAQUIN RIVER DELTA

Originally it had not been planned to sample diversions in the Sacramento-San Joaquin River Delta as a part of this study. However, the need to obtain more data on fish losses in this area, particularly in some of the pump diversions with fish screens of questionable effectiveness, and in the large siphon diversions, had existed for some time. Accordingly, as time permitted, fyke nets were fished in several Delta diversions during March and April, 1955. Most of the San Joaquin River diversions ceased taking fingerling salmon early in May of 1955, and all work was shifted from the San Joaquin River above Stockton into the Delta.

Salmon Migration Time

Upon reaching the Delta, Sacramento River king salmon fingerlings migrate down the main stem of the river and the principal diverging channels, Sutter, Steamboat, and Georgiana sloughs, more or less in proportion to their respective flows (Erkkila et al., 1950). Studies in the Delta in 1948 and 1949 showed that although most Sacramento River migrants moved directly downstream, considerable numbers also traveled by way of Georgiana Slough, Three Mile Slough, and Sherman Lake.

In 1949 the bulk of the Sacramento River juvenile salmon had passed through the Delta by the end of March, but some fish continued to enter the Delta until mid-June.

Fingerling salmon entering the Delta from the San Joaquin River in 1949 traveled principally along Middle River to Salmon Slough and Grant Line Slough, then down Old River. They did not enter the Delta until early April, and then continued to do so through the latter part of June. The seaward movement of these fish from the Delta was measurable through July.

At Martinez, located at the lower end of the Delta on Carquinez Strait, fingerling salmon migration records are available for 1939 and 1940 (Hatton and Clark, 1942). During these two years the majority of the fish migrated seaward between the last of February and the middle of May, with more than 80 percent of them descending during March.

Diversions Sampled and Fish Losses

In 1955 the East Contra Costa Irrigation District and the United States Bureau of Reclamation's Contra Costa Canal, both of which divert water from the Delta near the City of Antioch, were sampled for fish losses. Two large siphons on Ryer Island, which is situated on the Sacramento River side of the Delta just upstream from Rio Vista, were also sampled. The siphons included one operated by Reclamation District 501 and another by the Passaglia Brothers. Woodbridge Irrigation District's gravity flow diversion on the Mokelumne River was also sampled early in the season, but work was discontinued because of low water velocities in the canal, which rendered the sampling gear ineffective. All of the sampled diversions were found to be taking young salmon (Table 4). However, with the exception of the East Contra Costa Irrigation District diversion, it was not possible to determine fyke net efficiencies so as to compute a total loss for any test period, because of scarcity of live fish for marking.

The East Contra Costa Irrigation District diversion was the only diversion in the Delta on which studies were carried out over a significant period of time. This diversion is located 36½ miles upstream from the mouth of the San Joaquin River on Indian Slough. At the headworks of this diversion, located at the end of a 1½-mile-long canal leading from Indian Slough, there are six pumps, ranging in size from 18 to 30 inches in diameter. The average monthly flow through these pumps during April, May, and June for the five-year period 1948 through 1952 was slightly over 50 cubic feet per second. The studies indicated that over 6,000 fingerling salmon were destroyed between early April and mid-June in this canal.

TABLE 4

Diversions Sampled in the Sacramento-San Joaquin River Delta in 1955

Diversion	Location	Type, number, and size (diameter in inches) of diversion	Date	Hours of fyke netting	Number of juvenile salmon captured	Fyke net efficiency (percent)	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency and total possible hours of fyke netting during periods when salmon were captured
East Contra Costa Irrigation District	San Joaquin River near Antioch	Pump 2-18 2-24 2-30	Apr. 3-June 18[1]	610	234	10.5	2,228	6,148
United States Bureau of Reclamation, Contra Costa Canal	San Joaquin River near Antioch	Pump 1-30 2-42	May 29-June 18	113	20			
Reclamation District 501	Sacramento River at Ryer Island	Siphon 1-30	May 29-June 18	183	48			
Passaglia Brothers	Sacramento River at Ryer Island	Siphon 1-20	May 29-June 18	162	19			
Woodbridge Irrigation District	Mokelumne River at Woodbridge	Gravity	Mar. 27-May 7	326	3			

[1] No estimate May 15-21.

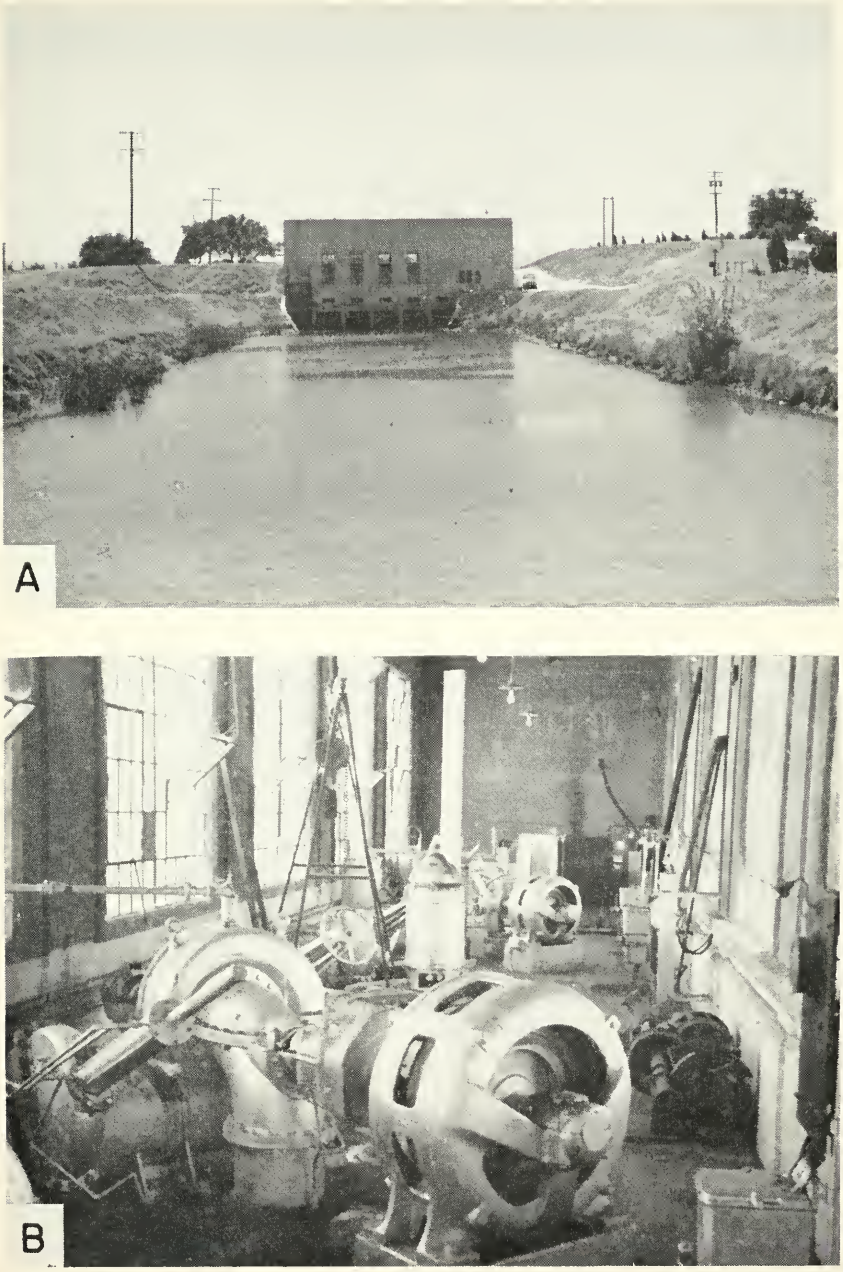

FIGURE 11. Two pumping plants in the Sacramento-San Joaquin River Delta at which fish losses were studied, 1955. A, The United States Bureau of Reclamation's Contra Costa Canal pumping plant; B, interior view of the East Contra Costa Irrigation District pumping plant. *Photographs by John E. Riggs.*

A summary of the individual diversions in the Delta sampled with fyke nets during 1955, along with the catches of all species, appears in the Appendix.

Conclusions (Sacramento-San Joaquin Delta)

Although the test periods were short, it was demonstrated that fish screens are needed at the East Contra Costa and Contra Costa canals, since considerable losses occur in these diversions. Further, the large siphons in the Delta are also destroying salmonids and other kinds of fishes. Additional study should be directed toward determining the extent of the siphon problems in the Delta, and the fish losses at the Woodbridge Irrigation District diversion.

SALMON MORTALITY

Since an efficient and economical fish screen for pump intakes has not been developed, the possibility of installing screens in canals to save juvenile salmon and steelhead after they have passed through the pumps was considered. Screens placed in canals below the pumps would be practical only if a large percentage of the young fish passed through the pumps alive and uninjured.

Studies showed that injuries received by fingerling salmon in passing through irrigation pumps in the Central Valley were similar to those listed by Schoeneman and Junge (1954) for downstream migrant salmon at dams on the Elwha River in Washington. Injuries which they commonly observed included: bulging or missing eyes, loss of scales, torn fins, ruptured abdomen, and "bisection." Although the causes of observed fish injuries were not determined in the present study, the injuries probably resulted in the ways suggested by Schoeneman and Junge, i.e., from pressure changes and mechanical causes, or a combination of the two. It was also found in the present study that some of the observed injuries, including missing eyes, loss of scales, torn fins, and ruptured abdomens, could result from use of a certain type of net in a high velocity discharge.

Since the causes of fish injuries were not definitely determined, and since in many cases pump injuries could not be distinguished from fyke net injuries, only the condition of salmon trapped in pump diversions at which fishing conditions were close to optimum for the available gear is covered in this report. The number of deaths resulting from latent injuries received in passing through the pumps was not determined, since live fish were returned to the river immediately or used to determine fyke net efficiencies.

Riffle fyke nets have been used successfully to live trap fingerling king salmon by Hallock, Warner, and Fry (1952) in velocities of 1 to 1½ feet per second. On the Sacramento River at the St. Patrick Home Ranch, where two of these nets were used to sample the discharge from an 18-inch centrifugal pump, 87.4 percent of the juvenile salmon taken were alive and apparently uninjured (Table 5). At the other Sacramento River diversions sampled, either velocities in the canals were unsuitable for efficient live trapping, or the numbers of salmon captured were too small to permit a reliable estimate of mortality.

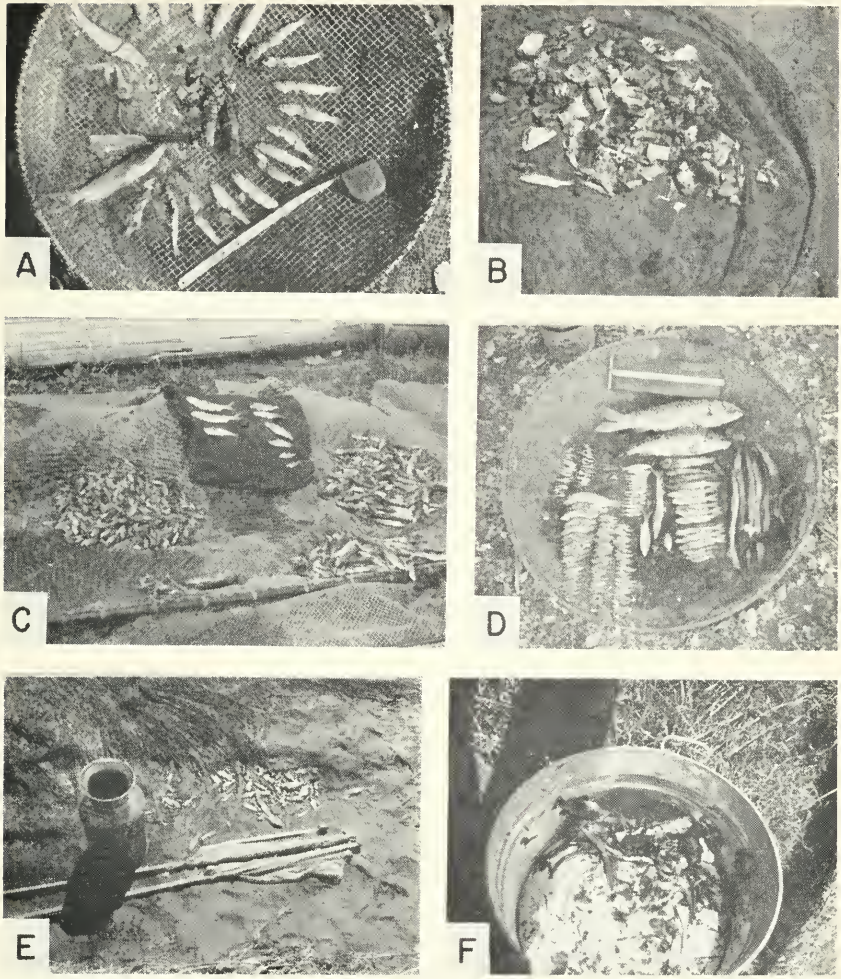

FIGURE 12. Typical daily fyke net catches (except E), showing the scarcity of salmonids, and the differences between fish which have passed, respectively, through centrifugal and screw-type pumps. A and F, Meridion Farms Water Company No. 1 and No. 2, showing cotfish, lampreys, sunfish, and salmon (A, right portion of circle); these fish passed through large centrifugal pumps; note whole fish up to 7 and 8 inches in length; B, Faxon, Morton, and P. Andreotti irrigation diversion, showing fish after passing through a screw-type pump; most of the fish have been cut into small pieces; C, D, and E, Olive Percy Davis et al irrigation diversion, showing catches of lampreys, carp, sunfish and some salmon; the fish up to 18 inches in length were passed "whole" through a 24-inch diameter centrifugal pump; after this canal was drained at the end of the irrigation season, all that remained were small cyprinids, sunfish, and catfish (E). *Photographs A, B, D, and F, by William F. Van Woert; and C, by Dalan R. Drane.*

Two rectangular fyke nets with aluminum perforated plate live boxes attached were used for diversion sampling along the San Joaquin River and in the Delta. Limited use of this type of net at a Sacramento River diversion had indicated that the live boxes would provide more reliable information on pump mortality.

TABLE 5

Survival of Juvenile Salmon Passing Through Irrigation Pumps

Water user	Salmon captured				
	Number			Percentage	
	Live	Dead	Total	Live	Dead
Sacramento River					
St. Patrick Home Ranch	898	129	1,027	87.4	12.6
San Joaquin River					
El Solyo Water Company	32	11	43	74.4	25.6
Banta-Carbona Irrigation District	36	136	172	20.9	79.1
Sacramento-San Joaquin River Delta					
Reclamation District No. 501	14	2	16	87.5	12.5
Passaglia Brothers	16	2	18	88.9	11.1
Contra Costa Canal (Bureau of Reclamation	18	1	19	94.7	5.3

As previously stated, the El Soyo Water Company and Banta-Carbona Irrigation District diversions on the San Joaquin River and the United States Bureau of Reclamation's Contra Costa Canal in the Delta were large, multiple pump plants. With a fyke net set in the canal near the discharge outlets of several pumps, it was often impossible to tell through which pump the fish had passed. Therefore, no information is available on the mortality caused by individual pumps.

Reclamation District 501 and Passaglia Brothers diversions in the Delta were both siphons, through which fingerling salmon should be able to pass without injury. The small numbers of dead salmon observed at these locations probably resulted from net injuries.

From the limited data obtained, it is evident that many juvenile salmon pass through some pumps alive (Table 5). In general, there appeared to be a tendency for fish to pass through some of the older centrifugal pumps alive and apparently uninjured, while passage through some of the newer screw-type pumps usually resulted in death and often "bisection."

BUTTE CREEK

King Salmon Migration

Butte Creek presents a rather unique problem to those managing its salmon populations, since it is theoretically possible for Feather River salmon, both young and adults, to use the lower end of Butte Creek as a migration route to and from the Sacramento River. This could be accomplished through the unscreened Western Canal Company diversion, leading from the Feather River near Oroville to Butte Creek near Durham. To further complicate the picture, adult salmon may also enter Butte Creek from the Sacramento River via Sacramento Slough and the Sutter Bypass without passing through the flap gates at the mouth of Butte Creek, which lead through a levee to the Sacramento River at Ward's Landing. Fingerling salmon are also free to use the latter route but, of course, they would be moving in the opposite direc-

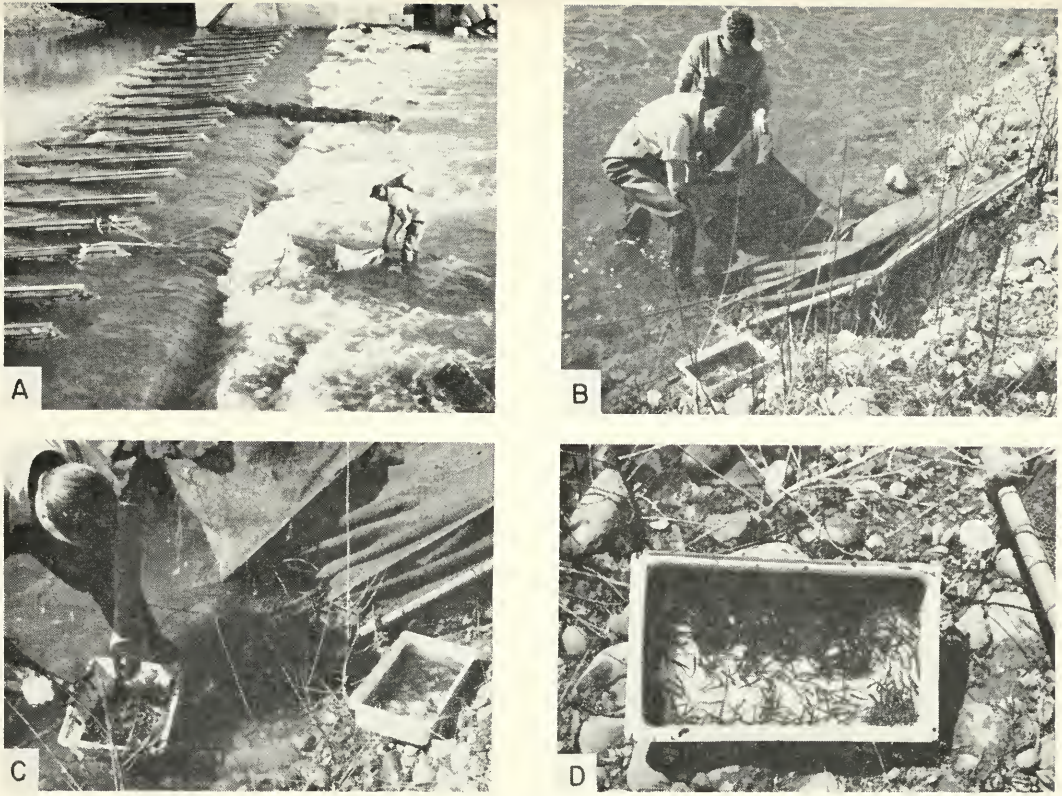

FIGURE 13. Determining the juvenile salmon migration time in Butte Creek. A, setting a fyke net below the apron of the Western Canal Company dam; this dam is a demountable structure, and the flashboards are not installed; B, examining the fyke net on shore, before removing the catch; C, sorting out the trash and examining captured salmon for marked fish; D, typical daily fyke net catch of salmon during the migration period. *Photographs by John E. Riggs.*

tion. There is evidence that salmon use these so-called secondary routes; however, the numbers involved are unknown.

Butte Creek supports an early spring run of adult king salmon, the bulk of which spawn in the 10-mile section below the Centerville Powerhouse in late September and early October. The remnants of a late fall run still persists, and occasionally considerable numbers of fish are able to find their way through the maze of commercial gun club and irrigation diversions from the lower stream to reach the spawning beds. Fall-run salmon were observed spawning in Butte Creek as far downstream as the Western Canal Company dam in 1956.

In March, April, and May, 1956, fyke nets were fished in Butte Creek below Gorrill Dam and the Western Canal Company dam, to determine the time of seaward salmon migration. However, only one juvenile salmon was captured during the entire three months, so it was apparent that there was either a poor hatch or the migration had taken place prior to the netting. Since flood conditions prevailed prior to the netting operation, it is probable that the scarcity of fish was due to both a poor hatch and an early but complete migration of fish from the eggs that did hatch.

In 1957, fyke netting was begun during December to determine the time of downstream migration. Fingerling salmon were found moving seaward in measurable quantities during the latter part of December, and the migration continued through the early part of March. The bulk of the fish moved out of the stream, or at least out of the area above the Western Canal Company diversion dam, in February.

Irrigation Season

The normal irrigation season on Butte Creek coincides with that of the Sacramento River above Sacramento, i.e., it does not get into full swing until late April and continues through September. However, some water is usually diverted from the lower section of Butte Creek through December by commercial gun clubs.

Diversions Sampled and Fish Losses

There are eight large unscreened irrigation diversions from Butte Creek, along a 25-mile section near Chico. Water enters six of them by gravity and is pumped into the other two. Lower Butte Creek also supports a host of diversions which supply water to commercial gun clubs and agricultural land. During part of each summer, water in the lower end of Butte Creek is supplemented and eventually replaced entirely by Feather River water, which is transported via the Western Canal Company ditch. The last of the Butte Creek water is usually diverted above the Western Canal Company dam.

In the spring of 1956, even though no juvenile salmon were being captured in fyke nets fished in Butte Creek, during April nets were also operated in irrigation diversions, including those of the Phelan-Parrott Irrigation System (often referred to as Parrott-Phelan) and Durham Mutual Water Company, Ltd., to further verify the scarcity of fingerlings. No salmon were captured. Since no fingerlings to study losses in the diversions were available, work was shifted toward the determination of the extent of adult spring-run salmon losses in these same diversions. It was soon found that many of these fish strayed into the

unscreened gravity-flow diversions and were unable to find their way back to the stream. For example, on April 25 about 40 adult salmon were visible at one time in the Western Canal Company diversion. These fish had passed from the creek into the canal through the headgates and were then concentrated in the canal near the headgates in an attempt to re-enter the creek. Reduction of the velocity of water entering the canal failed to induce any salmon to return to the creek. Later, observations revealed that these fish did not re-enter the creek and perished in the canal.

In May, 1956, adult salmon were again observed in the Western Canal Company diversion, as well as in the diversions leading from Adam's Dam and the Phelan-Parrott Dam. Adult salmon were also reported by sportsmen to be present in the Durham-Mutual Water Company canal.

Adult salmon were also observed in the Western Canal Company diversion during May, 1957, but estimates of the numbers involved were not obtained. Simple trash grids installed at irrigation diversion headworks would save many adult salmon each spring in Butte Creek.

In 1957, two diversions, Phelan-Parrott and Durham Mutual, were found to be operating unseasonally early. Each diverted water off and on during January and February, then shut down again. Fyke nets were fished in the canals during these periods, and again it was demonstrated that losses of salmon occur in unscreened diversions if water is being diverted when the salmon are migrating (Table 6).

In only one instance were sufficient tests conducted to determine the percentage of the fish migrating down Butte Creek taken by a particular diversion. These studies were made at the Phelan-Parrott Irrigation System's gravity flow diversion during a five-day period in the middle of January, 1957. As previously stated, this diversion was operated during the early part of the juvenile salmon migration, prior to the normal irrigation season. During the five days of testing, close to one-sixth of the juvenile salmon moving seaward past the intake were drawn into the canal, with only about 20 cubic feet of water per second being diverted.

Results of the limited tests on Butte Creek were not surprising in view of the findings of other workers. Wales and Coots (1955) found that salmon losses were approximately proportionate to the amount of water being diverted into a specially constructed test diversion from Fall Creek, Siskiyou County, California. For example, when 10 percent of the water was diverted, 10 percent of the migrating fish entered the gravity flow diversion. Studies by the Department of Fish and Game in the Los Molinos Mutual Water Company's lower diversion from Mill Creek during 1951 revealed that between February 20 and March 27, with a water flow into the ditch of between 16 and 35 cubic feet per second, about 10,000 fingerling salmon or one-seventh of the total downstream migrants which passed the intake were destroyed. At this same site, during a three-day period in the early part of April, 1951, when between 40 and 65 cubic feet of water per second was being diverted, close to one-fourth of the downstream migrants were drawn into the diversion.

A summary of the individual diversions sampled with fyke nets during 1957, along with the catches of all species, appears in the appendix.

TABLE 6

Diversions Sampled on Butte Creek, 1956 and 1957

Diversion	Location	Type of diversion	Date	Hours of fyke netting	Number of juvenile salmon captured	Fyke net efficiency (percent)	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency	Computed number of juvenile salmon captured, based on 100 percent fyke net efficiency and total possible hours of fyke netting during periods when salmon were captured
Phelan-Parrott Irrigation System*	Butte Creek near Chico	Gravity	Apr. 10-12, 1956 May 2-4, 1956	120				
Durham-Mutual Water Company, Ltd.; R. Bank	Butte Creek near Chico	Gravity	Apr. 10-12, 1956	48				
Phelan-Parrott Irrigation System*	Butte Creek near Chico	Gravity	Jan. 6-Feb. 9, 1957	256	118	15.2	776	2,545
Durham-Mutual Water Company, Ltd.; R. Bank	Butte Creek near Chico	Gravity	Feb. 3-Feb. 23, 1957	192	205	18.0	1,139	2,995

* Often referred to as Parrott-Phelan.

Conclusions (Butte Creek)

One might conclude from results of the 1956 and 1957 studies on Butte Creek that losses of fingerling salmon are so small that fish screens would be hard to justify economically under present agricultural practices. However, findings of the 1956 and 1957 work conflict with the results of tests made by the Department of Fish and Game at many of the same diversions in 1955. Whereas no fingerlings were present in Butte Creek in the spring of 1956 and none after mid-March in 1957, they were recovered in fair numbers in six of the eight diversions during the middle of April in 1955.

Variance in the test results points up the need for further work on this stream before a screening program for juvenile salmonids is adopted or abandoned. The loss of adult salmon in the diversions was amply demonstrated in 1956 and 1957, and the need for screens to protect them is obvious.

SUMMARY

There are more than 900 irrigation, industrial, and municipal water supply diversions above the Sacramento-San Joaquin River Delta from stream sections utilized by salmon, steelhead, and other anadromous fishes as migration routes to and from the sea. Most of these diversions are for irrigation. Practically all irrigation water diverted from the Sacramento and San Joaquin rivers is pumped.

In 1953 the California Department of Fish and Game initiated a survey of the Central Valley diversions and of the over-all salmon and steelhead losses occurring in them. Specific fish loss data were also sought for particular diversions under consideration for screening in the near future. The study was especially aimed at determining king salmon losses.

The method of diversion sampling consisted of fishing fyke nets of various types in the canals and releasing marked fish to determine net efficiencies.

Adult king salmon migrate into the upper Sacramento River system during all months of the year. There are three main runs: winter, spring, and fall.

There is a measurable seaward migration of fingerling salmon in the Sacramento River near Balls Ferry between early October and the latter part of May in most years. However, the majority of the fish migrate out of the upper river between early December and late April. In the upper river, during periods of normal flow, fingerlings migrate downstream fairly uniformly across the river and principally at depths varying from the surface to four feet. They move in greatest numbers between two and four feet. In the lower Sacramento River near Hood, the seaward migration occurs between mid-December and early June, with maximum numbers migrating in February and March.

The irrigation season along the Sacramento River between Sacramento and Redding extends from March to October. However, only 0.5 percent of the total seasonal volume used for irrigation is diverted in March and 8.4 percent in April.

In 1953 there were 335 separate diversions, utilizing a combined total of 448 pumps, along the Sacramento River between Redding and Sacramento. In 1953, 294 diversions, including 371 pumps, were sur-

veyed. Factors which might influence the take of fish were listed. Twenty-three diversions were sampled intermittently for fish losses. In 1954, nine diversions near Colusa were sampled during the entire irrigation season.

Although some losses occurred during the entire irrigation seasons, the numbers of juvenile salmon and steelhead destroyed at individual diversions were quite small in 1953 and 1954. The greatest seasonal loss at one diversion consisted of about 2,000 young salmon and 110 yearling steelhead.

The small juvenile salmon losses encountered are not surprising, since fyke netting has shown that during years of normal runoff most of the fish migrate out of the upper river before the start of the main irrigation season. Evidence that considerable losses of adult salmon and steelhead occur at pump intakes which do not have trash grids or screens was gathered.

The adult king salmon migrations in the San Joaquin River system during recent years have consisted almost entirely of fall-run fish which spawn in the tributaries from the Merced to the Cosumnes rivers. The once large upper San Joaquin spring run was destroyed by 1949 as a result of the lack of flow releases from Friant Dam. The present fall run usually takes place a few weeks later than the Sacramento River fall run.

The seaward migration of San Joaquin River juvenile salmon usually peaks in the Stockton area some time in March.

The irrigation season along the San Joaquin River between the mouth of the Merced River and Stockton usually runs from early March through October, with some water diverted in February and November. On the average, about 5.8 percent of the water used for irrigation is diverted in March and 14.1 percent in April.

In 1955 there were 113 separate diversions, utilizing 159 pumps, along the San Joaquin River between Stockton and Newman (Fremont Ford). Three diversions were sampled during the time of the salmon fingerling seaward migration. All were found to be destroying more fingerling salmon than any of those sampled during the previous two years along the upper Sacramento. The expectancy of fish losses in diversions along the San Joaquin is illustrated not only by the coincidence of the irrigation season with the salmon migration, but also by the large proportion of San Joaquin flows which is diverted early in the irrigation season, during the salmon migration period.

A limited amount of diversion sampling was done in the Sacramento-San Joaquin River Delta in April, May and June, 1955, at pumps as well as siphons. All sampled diversions were found to be taking fingerling salmon.

By the end of June the last salmon fingerlings from the two river systems have usually entered the Delta. The seaward movement from the Delta is measurable through July. Close to 80 percent of the migrants pass through the Delta during March.

Many juvenile salmon pass through the pumps alive. In general, the centrifugal type pump appears to pass more fish alive than the screw type.

In 1956 and 1957, diversion sampling was also done on Butte Creek. Butte Creek supports an early spring run of adult king salmon. The fall run is small.

The seaward migration of fingerling salmon in Butte Creek occurred from the latter part of December through the early part of March in 1957, with practically all of the fish having moved out of the upper reaches by the end of February.

The normal irrigation season along Butte Creek extends from late April to late September.

There are eight large unscreened diversions on Butte Creek near Chico. Fyke nets were fished in two of these diversions, as well as at two points in the stream. The study showed that practically all of the fingerling salmon migrated out of the stream before the irrigation seasons started in 1956 and 1957. These results are in conflict with the findings of studies made in 1955, which showed that fingerling salmon losses in these same diversions occurred as late as mid-April.

The loss of adult salmon in Butte Creek diversions, particularly the Western Canal Company ditch, was demonstrated in 1956 and 1957. It is concluded that screens are necessary to protect them.

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APPENDIX

TABLE A-1

List of Common and Scientific Names of Fishes Captured in Fyke Nets During the Irrigation Diversion Survey

Common name	Scientific name
Family Petromyzontidae. The Lamprey Family.	
1. Pacific lamprey	*Entosphenus tridentatus* (Gairdner)
2. Brook lamprey	*Lampetra planeri* (Bloch)
Family Acipenseridae. The Sturgeon Family.	
3. White sturgeon	*Acipenser transmontanus* Richardson
Family Clupeidae. The Herring Family.	
4. American shad	*Alosa sapidissima* (Wilson)
Family Osmeridae. The Smelt Family.	
5.	Unknown
Family Salmonidae. The Salmon and Trout Family.	
6. King salmon	*Oncorhynchus tshawytscha* (Walbaum)
7. Steelhead rainbow trout	*Salmo gairdnerii gairdnerii* Richardson
Family Catostomidae. The Sucker Family.	
8. Sacramento western sucker	*Catostomus occidentalis occidentalis* Ayres
Family Cyprinidae. The Carp or Minnow Family.	
9. Carp	*Cyprinus carpio* Linnaeus
10. Sacramento blackfish	*Orthodon microlepidotus* (Ayres)
11. Sacramento hitch	*Lavinia exilicauda exilicauda* Baird and Girard
12. Sacramento squawfish	*Ptychocheilus grandis* (Ayres)
13. Splittail	*Pogonichthys macrolepidotus* (Ayres)
Family Ictaluridae. The Catfish Family.	
14. Channel catfish	*Ictalurus punctatus* (Rafinesque)
15. White catfish	*Ictalurus catus* (Linnaeus)
16. Brown bullhead	*Ictalurus nebulosus* (LeSueur)
Family Poeciliidae. The Topminnow Family.	
17. Mosquitofish	*Gambusia affinis* (Baird and Girar
Family Pleuronectidae. The Righteyed Flounder Family.	
18. Starry flounder	*Platichthys stellatus* (Pallas)
Family Serranidae. The Sea Bass Family.	
19. Striped bass	*Roccus saxatilis* (Walbaum)
Family Centrarchidae. The Sunfish Family.	
20. Largemouth bass	*Micropterus salmoides* (Lacé pè de)
21. Warmouth bass	*Chaenobryttus gulosus* (Cuvier)
22. Green sunfish	*Lepomis cyanellus* Rafinesque
23. Bluegill	*Lepomis macrochirus* Rafinesque
24. Black crappie	*Pomoxis nigromaculatus* (LeSueur)
Family Embiotocidae. The Viviparous Perch Family.	
25. Tule perch	*Hysterocarpus traskii* Gibbons
Family Cottidae. The Sculpin Family.	
26. Sculpin	*Cottus* sp.
Family Gasterosteidae. The Stickleback Family.	
27. Threespine stickleback	*Gasterosteus aculeatus* Linnaeus

TABLE A-2

Sacramento River Irrigation Pump Survey, 1953

Size of pump (diameter in inches)	Number of pumps surveyed*				Number of pumps listed†		
	Turbine	Centrifugal	Screw type	Total	Diverting water	Not diverting water	Total
1¼	1			1	1		1
1½		2		2	2		2
2		1		1	3	1	4
2½		4		4	5		5
3		6		6	4	2	6
4		8		8	9	2	11
5		7		7	11	1	12
6	1	28		29	25	11	36
7		3		3	2	2	4
8	4	28	2	34	35	5	40
10	10	36	1	47	45	8	53
12	16	37	8	61	56	8	64
14	14	12	7	33	31	5	36
15		5		5	5	1	6
16	27	8	1	36	37	4	41
18	3	11	1	15	16	2	18
20	10	8	1	19	23	1	24
22	4	1		5	5		5
24	10	16		26	35		35
28					1		1
30	2	1		3	3		3
32	2			2	2		2
36	1	6		7	8		8
38					2		2
42	5	7		12	12		12
48	2			2	4		4
50		3		3	4		4
54					1		1
66					4		4
72					3		3
100					1		1
Totals	112	238	21	371	395	53	448

* It was not determined whether the turbines had centrifugal or screw-type runners because only external examination of the pump was possible. The screw-type pumps may also have been turbines but this was not determined for the same reason.

† Report of Sacramento-San Joaquin Water Supervision for 1953.

TABLE A-3

Sacramento River, Diversion Sampling: Number of Fish Trapped in the Canal During the 1953 Irrigation Season

Species of fish captured (common name)	Anderson-Cottonwood Irrigation District[1]	Olive Percy Davis et al. 78.8 R[2]	Reclamation District No. 1004	R. Pheiffer
	Apr. 6-Aug. 20	July 27-Aug. 13	June 3-18	May 28-30
King salmon (Fork length in inches)				
1.0-1.4	17			
1.5-1.9	34			
2.0-2.4				
2.5-2.9				
3.0-3.4		1		
3.5-3.9		1	1	
4.0-4.4		3		
4.5-4.9		11		
5.0-5.4		7		
5.5-5.9		2		
6.0-6.4		1		
Not measured	85			
Totals	136	26	1	
Adult king salmon				
Steelhead rainbow trout				
Pacific lamprey		1	1	
Brook lamprey				
Ammocoete (species?)	2	1		
American shad				
Sacramento western sucker		382		
Carp		146		
Sacramento squawfish				
Splittail		2		
Unidentified minnows		362		
White catfish	6	22	1	
Mosquitofish		3		
Largemouth bass		7		
Green sunfish		1,785	1	
Warmouth				
Tule perch		2		
Sculpin (species?)		130	5	
Threespine stickleback	23			
Tadpole				
Crayfish		1	9	

No fish captured

[1] All of the king salmon were captured during the period April 6-16, 1953. Combined catch of two nets.

[2] Pump broke down during night of July 27; time unkown. An estimated 2,500 sunfish, minnows and suckers trapped on July 29 are not included in these totals.

TABLE A-3—Continued

Sacramento River, Diversion Sampling: Number of Fish Trapped in the Canal During the 1953 Irrigation Season

Species of fish captured (common name)	V. G. Strain	Provident Irrigation District	Princeton-Codora Glenn Irrigation District 123.9 R[3]	Princeton-Codora Glenn Irrigation District 112.4 R
	June 16-17	June 23-25	June 2-4	June 3-9
King salmon (Fork length in inches)				
1.0-1.4				
1.5-1.9				
2.0-2.4				
2.5-2.9				
3.0-3.4				
3.5-3.9				
4.0-4.4				
4.5-4.9				
5.0-5.4				
5.5-5.9				
6.0-6.4				
Not measured				
Totals				
Adult king salmon				
Steelhead rainbow trout				
Pacific lamprey	No fish captured			
Brook lamprey			1	5
Ammocoete (species?)				
American shad				
Sacramento western sucker				
Carp				
Sacramento squawfish		1		
Splittail				
Unidentified minnows		4		1
White catfish				2
Mosquitofish				
Largemouth bass				
Green sunfish				
Warmouth				
Tule perch			1	
Sculpin (species?)		1		4
Threespine stickleback		14		
Tadpole		2		16
Crayfish		1		1

[3] Combined catch of two nets.

TABLE A-3—Continued

Sacramento River, Diversion Sampling: Number of Fish Trapped in the Canal During the 1953 Irrigation Season

Species of fish captured (common name)	Hollis Sartain July 29-30	Azro N. Lewis Aug. 10-13	Roger Wilbur 95.25 L[4] July 28-30	Roger Wilbur 87.4 R[5] July 27-28
King salmon (Fork length in inches)				
1.0-1.4				
1.5-1.9				
2.0-2.4				
2.5-2.9				
3.0-3.4				
3.5-3.9				
4.0-4.4				
4.5-4.9				
5.0-5.4				
5.5-5.9				
6.0-6.4				
Not measured				
Totals				
Adult king salmon				
Steelhead rainbow trout				
Pacific lamprey	No fish captured		No fish captured	
Brook lamprey				
Ammocoete (species?)				
American shad				
Sacramento western sucker		1		
Carp		13		1
Sacramento squawfish				
Splittail				
Unidentified minnows				
White catfish				
Mosquitofish				
Largemouth bass				
Green sunfish		4		
Warmouth				
Tule perch				
Sculpin (species?)				1
Threespine stickleback				
Tadpole				
Crayfish				

[4] Not enough velocity to make a good set; periodic water changing among ditches.
[5] Entire discharge sampled.

TABLE A-3—Continued

Sacramento River, Diversion Sampling: Number of Fish Trapped in the Canal During the 1953 Irrigation Season

Species of fish captured (common name)	Wayne Hall July 14-17	Meridian Farms Water Company No. 1 and No. 2 July 15-17	Olive Percy Davis et al. 78.75 R Aug. 10-13	Robert Chesney J. H. Yates Estate[6] July 14-17
King salmon (Fork length in inches)				
1.0-1.4				
1.5-1.9				
2.0-2.4				
2.5-2.9				
3.0-3.4				
3.5-3.9				
4.0-4.4				
4.5-4.9				
5.0-5.4				
5.5-5.9				
6.0-6.4				
Not measured				
Totals				
Adult king salmon				
Steelhead rainbow trout				
Pacific lamprey		1		
Brook lamprey		1		
Ammocoete (species?)		1		
American shad				
Sacramento western sucker	5	1	2	1
Carp	7	4		23
Sacramento squawfish	2	1		1
Splittail			1	
Unidentified minnows		1	2	
White catfish	3	1		120
Mosquitofish				
Largemouth bass				
Green sunfish	2	1	34	2
Warmouth				
Tule perch			2	
Sculpin (species?)			2	1
Threespine stickleback				
Tadpole				
Crayfish	27	25		10

[6] These pumps discharge into the same basin, both pumps were operating during sampling.

TABLE A-3—Continued

Sacramento River, Diversion Sampling: Number of Fish Trapped in the Canal During the 1953 Irrigation Season

Species of fish captured (common name)	Meridian Farms Water Company No. 3 July 15-17	Meridian Farms Water Company No. 4[7] Aug. 10-13	Faxon, Morton and P. Andreotti July 27-30	J. L. Browning[8] July 28
King salmon (Fork length in inches)				
1.0-1.4				
1.5-1.9				
2.0-2.4				
2.5-2.9				
3.0-3.4				
3.5-3.9				
4.0-4.4				
4.5-4.9				
5.0-5.4				
5.5-5.9				
6.0-6.4				
Not measured				
Totals				
Adult king salmon		22		
Steelhead rainbow trout		1		
Pacific lamprey				No fish captured
Brook lamprey				
Ammocoete (species?)				
American shad				
Sacramento western sucker			1	
Carp			1	
Sacramento squawfish				
Splittail				
Unidentified minnows			1	
White catfish				
Mosquitofish				
Largemouth bass				
Green sunfish				
Warmouth				
Tule perch	1	2	1	
Sculpin (species?)				
Threespine stickleback				
Tadpole				
Crayfish			1	

[7] An estimated 60-70 dead salmonids (6-24 inches in length) observed in ditch August 10-12, 1953.
[8] Only the 14-inch pump operated during sampling.

TABLE A-3—Continued

Sacramento River, Diversion Sampling: Number of Fish Trapped in the Canal During the 1953 Irrigation Season

Species of fish captured (common name)	Newhall Land and Farming Company July 14-17	Natomas Central Mutual Water Company Aug. 18-19
King salmon (fork length in inches)		
1.0-1.4		
1.5-1.9		
2.0-2.4		
2.5-2.9		
3.0-3.4		
3.5-3.9		
4.0-4.4		
4.5-4.9		
5.0-5.4		
5.5-5.9		
6.0-6.4		
Not measured		
Totals		
Adult king salmon		
Steelhead rainbow trout		
Pacific lamprey		
Brook lamprey		
Ammocoete (species ?)	2	
American shad		1
Sacramento western sucker		
Carp	16	1
Sacramento squawfish		
Splittail		
Unidentified minnows	39	
White catfish	2	2
Mosquitofish		
Largemouth bass		
Green sunfish	1	
Warmouth		1
Tule perch		
Sculpin (species?)	1	
Threespine stickleback		
Tadpole	1	
Crayfish	1	

TABLE A-4

Sacramento River; Olive Percy Davis et al. Diversion, 78.8 R *: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9	2												2
2.0-2.4	3	17	1										21
2.5-2.9	6	18	6					1					31
3.0-3.4	3	25	11	3	15	1	1						59
3.5-3.9		8	16	14	36	12	4	1					91
4.0-4.4		2	4	8	9	9	12	1					45
4.5-4.9				2	1	2	1	1	1				8
5.0-5.4		1	1				1						3
Not measured	1	17	3	9	7	3			3				43
Totals	15	88	42	36	68	27	19	4	4				303
Adult king salmon										1			1
Steelhead rainbow trout	3	11	1		4				1				20
Pacific lamprey	7	8	1	9	80	24	6	8	2				145
Brook lamprey	58	150	41	3	7								259
Ammocoete (species?)	5	1					1						7
White sturgeon		2			1								3
American shad													
Sacramento western sucker	1	4	7	1	6		17	4	17	14			71
Carp	30	164	2	46	234	198	127	80	34	18			933
Sacramento blackfish					1								1
Sacramento hitch													8
Sacramento squawfish	1	7											
Splittail													
Unidentified minnows	8	152	3	17	330	392	36	17	13	3			971
Channel catfish						2	1	3					6
White catfish	7	24	8	14	68	42	24	11	3	10			211
Brown bullhead		1				11		1					13
Mosquitofish					1								1
Striped bass		1						1					2
Largemouth bass	3	97		1	45		2	3	2	6			159
Green sunfish	1	8	2	2	3	973	112	15	48	6			1,170
Bluegill													
Black crappie					9		1						10
Tule perch		2		1	4				1				8
Sculpin (species?)			1		22	50	35	4	3				115
Tadpole		7			3	1			1				12
Crayfish		11	6		4	2	2	1	1				27

* Mile and bank above Sacramento.

TABLE A-5

Sacramento River; Meridian Farms Water Company No. 1 and No. 2 Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9	1												1
2.0-2.4	11												11
2.5-2.9	8	1			1								10
3.0-3.4		2	1		2								5
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured	1				3								4
Totals	21	3	1		6								31
Adult king salmon		1			1	1	1	2	1	2	1		10
Steelhead rainbow trout	4					3		1	1				9
Pacific lamprey	10	1	1	1	16	7	7	3					46
Brook lamprey	185	28	13	5	5	1							237
Ammocoete (species?)	4	5	2	6	9	1	3	6	4	2			42
White sturgeon													
American shad													
Sacramento western sucker	3		1	1	1	2	1	1	9	3			22
Carp	13	49	3	506	127	68	15	10	15	9	2		817
Sacramento blackfish	1	1		8	5	3							18
Sacramento hitch							1		2	1	11		15
Sacramento squawfish	4			1									5
Splittail						1							1
Unidentified minnows	5	1	1		2	2	6	2		1	1		21
Channel catfish		2	1	1	1	2		3					10
White catfish	35	27	11	19	128	69	90	59	23	29	19		509
Brown bullhead	3	1			10	188	7			4	2		245
Mosquitofish													
Striped bass		52		2	1				1				56
Largemouth bass	7	59			4						1		71
Green sunfish	7	1		2	2	2	2	2		2			20
Bluegill	1												1
Black crappie			1	1									2
Tule perch	6	2		3	8	1	3	4	3	5			35
Sculpin (species?)	6	1	2	5	11	3	4	2	2	2			38
Tadpole	1	9	2	1	2						1		16
Crayfish	62	99	70	158	290	91	64	92	91	47	11		1,075

TABLE A-6

Sacramento River; St. Patrick Home Ranch Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	Mar. 1-13	Mar. 14-27	Mar. 28-Apr. 10	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	July 4-17	July 18-31	Aug. 1-14	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4	202	24			21								247
1.5-1.9	438	126			32								596
2.0-2.4	9	7											16
2.5-2.9	1	1				2							4
3.0-3.4													
3.5-3.9													
4.0-4.4	2												2
4.5-4.9													
5.0-5.4													
Not measured	389	11			1								401
Totals	1,041	169			54	2							1,266
Adult king salmon	1												1
Steelhead rainbow trout	1				1								2
Pacific lamprey	10	15			2								27
Brook lamprey	5												5
Ammocoete (species?)	32	4			4	11							51
White sturgeon													
American shad													
Sacramento western sucker	11				2	8				1			22
Carp						4				3			7
Sacramento blackfish													
Sacramento hitch	1												1
Sacramento squawfish	2												2
Splittail													
Unidentified minnows													
Channel catfish													
White catfish	1					21				11	1		34
Brown bullhead	1												1
Mosquitofish													
Striped bass										2			2
Largemouth bass													
Green sunfish		1											1
Bluegill													
Black crappie													
Tule perch	3					7				1			11
Sculpin (species?)	8	1			1	3				2	1		16
Tadpole													
Crayfish	2					8				5	3		18

TABLE A-7

Sacramento River; Wayne Hall Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9													
3.0-3.4													
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured				1									1
Totals				1									1
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey													
Brook lamprey													
Ammocoete (species?)					1		2		1	3	2		9
White sturgeon													
American shad													
Sacramento western sucker				1	45	113	23	4	4	16	1		207
Carp				49	11	9	2	39	12	14	110	9	255
Sacramento blackfish								1		10	1		12
Sacramento hitch								2					2
Sacramento squawfish								1					1
Splittail													
Unidentified minnows				60	32	87	2	19	8		4		212
Channel catfish													
White catfish				13	19	21	3	7	2	1	5	2	73
Brown bullhead					7	8	1		1		1		18
Mosquitofish													
Striped bass													
Largemouth bass				4	1			13	11	5	3		37
Green sunfish											1	5	6
Bluegill													
Black crappie									1				1
Tule perch				3	4	1		4					12
Sculpin (species?)				3	2		1	3	2	3			14
Tadpole							1						1
Crayfish				62	81	50	19	31	46	43	58	16	406

TABLE A-8

Sacramento River; Olive Percy Davis et al. Diversion, 78.75 R *: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9													
3.0-3.4				2									2
3.5-3.9				11									11
4.0-4.4				4									4
4.5-4.9													
5.0-5.4													
Not measured		1											1
Totals		1		17									18
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey		4											4
Brook lamprey	9	37		1									47
Ammocoete (species?)		1											1
White sturgeon													
American shad													
Sacramento western sucker		1		1									2
Carp		31											31
Sacramento blackfish													
Sacramento hitch													
Sacramento squawfish													
Splittail													
Unidentified minnows	3			1									4
Channel catfish													
White catfish		2		3									5
Brown bullhead													
Mosquitofish													
Striped bass		61											61
Largemouth bass		23											23
Green sunfish		4											4
Bluegill													
Black crappie													
Tule perch		2											2
Sculpin (species?)													
Tadpole		3											3
Crayfish		3		3									6

* Mile and bank above Sacramento.

TABLE A-9

Sacramento River; Meridian Farms Water Company No. 3 Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9		1											1
2.0-2.4													
2.5-2.9													
3.0-3.4													
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured	1												1
Totals	1	1											2
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey													
Brook lamprey	1												1
Ammocoete (species?)	3	3	1			2	3	1					13
White sturgeon													
American shad													
Sacramento western sucker								2	2	1			5
Carp	1	7	8	13	8	1	1						39
Sacramento blackfish													
Sacramento hitch													
Sacramento squawfish													
Splittail													
Unidentified minnows		4	6	6	4	1							21
Channel catfish													
White catfish		1		1	4	9	1	3	1				20
Brown bullhead							6	1	3				10
Mosquitofish							1						1
Striped bass		65											65
Largemouth bass	6	41	1	1	4			1					54
Green sunfish	1	22	18		1	1							43
Bluegill	1												1
Black crappie		36	21	17	3			1					78
Tule perch		1	2	12	3		1	1	1				21
Sculpin (species?)	3	2	1	3	2		1	2	1		1		16
Tadpole	4	19	12	9	3								47
Crayfish	4	15	9	20	18	2	4	5	1	1			79

TABLE A-10

Sacramento River; Meridian Farms Water Company No. 4 Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9		1											1
3.0-3.4													
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured		1											1
Totals		2											2
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey	1	1											2
Brook lamprey	34	6											40
Ammocoete (species?)	3	1											4
White sturgeon													
American shad													
Sacramento western sucker		1											1
Carp		5											5
Sacramento blackfish													
Sacramento hitch													
Sacramento squawfish		1											1
Splittail													
Unidentified minnows		6											6
Channel catfish													
White catfish	11	4											15
Brown bullhead		2											2
Mosquitofish													
Striped bass		3											3
Largemouth bass		24											24
Green sunfish		2											2
Bluegill													
Black crappie													
Tule perch	4	1											5
Sculpin (species?)	6												6
Tadpole		3											3
Crayfish	9	11											20

TABLE A-11

Sacramento River; Hoffman, Beckley, Ritchie, Poundstone, and Andreotti Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	Mar. 28–April 10	April 11–24	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9													
3.0-3.4							1						1
3.5-3.9													
4.0-4.4									1				1
4.5-4.9													
5.0-5.4									1				1
Not measured													
Totals							1		2				3
Adult king salmon													
Steelhead rainbow trout								1		1			2
Pacific lamprey													
Brook lamprey		2											2
Ammocoete (species?)							1						1
White sturgeon													
American shad													
Sacramento western sucker						5	5			2	5	6	23
Carp						5	9	5	2	3	2	2	28
Sacramento blackfish											2		2
Sacramento hitch											39	17	56
Sacramento squawfish													
Splittail											1		1
Unidentified minnows						5	303	9	24	47	22		410
Channel catfish								2		1		1	4
White catfish						14	24	19	25	41	15	5	143
Brown bullhead						1	1			2	1	2	7
Mosquitofish											1		1
Striped bass													
Largemouth bass							3		1			1	5
Green sunfish													
Bluegill													
Black crappie						1							1
Tule perch						1	2	2		1	8	1	15
Sculpin (species?)							9			1	2	1	13
Tadpole							3						3
Crayfish		1				16	31	8	23	22	19		120

TABLE A-12

Sacramento River; Faxon, Morton, and P. Andreotti Diversion: Number of Fished Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9													
3.0-3.4													
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured													
Totals													
Adult king salmon													
Steelhead rainbow trout									1				1
Pacific lamprey													
Brook lamprey													
Ammocoete (species?)				5	7	2	5	4	3				26
White sturgeon													
American shad					2								2
Sacramento western sucker							2	2	27	1			32
Carp				25	57	12	9	5	3				111
Sacramento blackfish					2								2
Sacramento hitch										1			1
Sacramento squawfish													
Splittail													
Unidentified minnows				1	1		3		1	1			7
Channel catfish													
White catfish				1	15	7	9	3	2				37
Brown bullhead													
Mosquitofish													
Striped bass					4		1						5
Largemouth bass					1								1
Green sunfish				1	1	1							3
Bluegill													
Black crappie													
Tule perch				2	10		8	3	13				36
Sculpin (species?)					3	2	1	1	1	2			10
Tadpole				1									1
Crayfish				1	42	18	23	31	22	6			143

TABLE A-13

Sacramento River; Tisdale Irrigation and Drainage Company Diversion, 67.1 L*: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9													
3.0-3.4													
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured													
Totals													
Adult king salmon													
Steelhead rainbow trout	2												
Pacific lamprey													
Brook lamprey	1		1										2
Ammocoete (species?)	4	1											5
White sturgeon													
American shad													
Sacramento western sucker													
Carp	1	18	14	10									43
Sacramento blackfish													
Sacramento hitch													
Sacramento squawfish													
Splittail													
Unidentified minnows	39	2		1									42
Channel catfish													
White catfish	2	1											3
Brown bullhead													
Mosquitofish													
Striped bass		62											62
Largemouth bass	4	11											15
Green sunfish				1									1
Bluegill		8											8
Black crappie		3	10										13
Tule perch			1										1
Sculpin (species?)		1											1
Tadpole			1	1									2
Crayfish			1										1

* Mile and bank above Sacramento.

TABLE A-14

Sacramento River; Sutter Mutual Water Company Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4					1								1
1.5-1.9			9	1									10
2.0-2.4			12	2	1	1							16
2.5-2.9			3	2		1							6
3.0-3.4							1						1
3.5-3.9									1				1
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured			3	1		3	1	1					9
Totals			27	6	2	5	2	1	1				41
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey													
Brook lamprey			13	1									14
Ammocoete (species?)			6	1			4		2				13
White sturgeon													
American shad													
Sacramento western sucker							1		6				7
Carp			1	58	27	30	41	19	17		1		194
Sacramento blackfish				3					1		1		5
Sacramento hitch													
Sacramento squawfish					1								1
Splittail													
Unidentified minnows			2	8	1	1	5						17
Channel catfish													
White catfish			4	1	1	2	7	2	1				18
Brown bullhead													
Mosquitofish													
Striped bass													
Largemouth bass			1		1	3			1		1		7
Green sunfish				8	5	3	10	1	3				30
Bluegill				1		1							2
Black crappie				2				1			1		4
Tule perch			1	15	11	2	4	3	1		1		38
Sculpin (species?)			1				2						3
Tadpole			5	1			2						8
Crayfish			2	27	122	63	65	46	17				342

TABLE A-15

Sacramento River; W. A. Larner Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25 May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9													
2.0-2.4													
2.5-2.9													
3.0-3.4			1										1
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured				1									1
Totals			1	1									2
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey		1							1				2
Brook lamprey			1	5									6
Ammocoete (species?)			3	2	6		1						12
White sturgeon													
American shad													
Sacramento western sucker											1		1
Carp		3	3	28	3	3					14	2	56
Sacramento blackfish					1								1
Sacramento hitch													
Sacramento squawfish													
Splittail													
Unidentified minnows				4	3								7
Channel catfish											1		1
White catfish		4	6	22	10	10	7	25	3		1		88
Brown bullhead							1						1
Mosquitofish													
Striped bass					1	1	1						3
Largemouth bass		32	1		2								35
Green sunfish		2	2	1	5		1	2	1		1	2	17
Bluegill													
Black crappie				1									1
Tule perch			10	23	14	4	2	2	1	1	2		59
Sculpin (species?)					1								1
Tadpole			1	1									2
Crayfish		18	28	54	65	24	32	34	20	10	20	4	309

TABLE A-16

Sacramento River; Thousand Acre Ranch (H. W. Keller) Diversion: Number of Fish Trapped in the Canal During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 25–May 8	May 9–22	May 23–June 5	June 6–19	June 20–July 3	July 4–17	July 18–31	Aug. 1–14	Aug. 15–28	Aug. 29–Sept. 11	Sept. 12–25	Sept. 26–Oct. 9	Seasonal total
King salmon (Fork length in inches)													
1.0-1.4													
1.5-1.9	3												3
2.0-2.4													
2.5-2.9	1												1
3.0-3.4													
3.5-3.9													
4.0-4.4													
4.5-4.9													
5.0-5.4													
Not measured													
Totals	4												4
Adult king salmon													
Steelhead rainbow trout													
Pacific lamprey	5												5
Brook lamprey	4												4
Ammocoete (species?)													
White sturgeon													
American shad													
Sacramento western sucker													
Carp			15										15
Sacramento blackfish													
Sacramento hitch													
Sacramento squawfish			1										1
Splittail													
Unidentified minnows	3	4	1										8
Channel catfish													
White catfish	2												2
Brown bullhead													
Mosquitofish													
Striped bass		1											1
Largemouth bass													
Green sunfish		1											1
Bluegill	1												1
Black crappie													
Tule perch													
Sculpin (species?)	1												1
Tadpole													
Crayfish													

TABLE A-17

Sacramento River; Diversion Sampling: Number of Fish Trapped in the Canals During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	Reclamation District No. 1004	Charles W. Welch	Nettie, George and Ella Packer		Mayfair Packing Company	Howell Davis
	Apr. 25-May 8	Apr. 25-May 8	May 9-22	May 23-June 5	Sept. 26-Oct. 9	July 4-17
King salmon (Fork length in inches)						
1.0-1.4						
1.5-1.9	2					
2.0-2.4	1					
2.5-2.9	1			1		
3.0-3.4						
3.5-3.9						
4.0-4.4						
4.5-4.9						
5.0-5.4						
Not measured	1	2				
Totals	5	2		1		
Adult king salmon						
Steelhead rainbow trout						
Pacific lamprey	1					
Brook lamprey	1					
Ammocoete (species?)	2	1	25	7		
White sturgeon						
American shad						
Sacramento western sucker	1					
Carp	1	7		1		
Sacramento blackfish						
Sacramento hitch						
Sacramento squawfish		1				
Splittail						
Unidentified minnows		2				
Channel catfish						
White catfish	2		3			
Brown bullhead		2				
Mosquitofish						
Striped bass						
Largemouth bass			1			
Green sunfish		5	1			
Bluegill		1	1			
Black crappie						
Tule perch	1				1	1
Sculpin (species?)	3	1	2	1		
Tadpole	4	2	5	1		
Crayfish	2		2		1	1

TABLE A-17—Continued

Sacramento River; Diversion Sampling: Number of Fish Trapped in the Canals During the 1954 Irrigation Season by Two-week Periods

Species of fish captured (common name)	J. H. Yates Estate	Newhall Land and Farming Company	Tisdale Irrigation and Drainage Company 64.4 L*			Sacramento River Ranch
	May 9-22	Apr. 25-May 8	May 23-June 5	Aug. 15-28	Sept. 12-25	May 9-22
King salmon (Fork length in inches)						
1.0-1.4						
1.5-1.9						
2.0-2.4						
2.5-2.9						3
3.0-3.4						1
3.5 3.9						1
4.0 4.4						
4.5-4.9						
5.0-5.4						
Not measured						2
Totals						7
Adult king salmon		1				
Steelhead rainbow trout						2
Pacific lamprey		3				1
Brook lamprey		39				
Ammocoete (species?)			2			
White sturgeon						
American shad						2
Sacramento western sucker						
Carp		10				9
Sacramento blackfish						
Sacramento hitch						
Sacramento squawfish						
Splittail						
Unidentified minnows		6				
Channel catfish						
White catfish	1	7	1		1	2
Brown bullhead		3				
Mosquitofish						
Striped bass	1	1				
Largemouth bass		5				1
Green sunfish						
Bluegill						
Black crappie						
Tule perch	1					
Sculpin (species?)		3				
Tadpole						
Crayfish		14	10	3	10	

* Mile and bank above Sacramento.

TABLE A-18

Sacramento River; Diversion Sampling: Number of Fish Trapped in Canals During the 1955 Irrigation Season by Two-week Periods

	L. W. Seaver 99.3 R*	Meridian Farms Water Company No. 1 and No. 2, 80.0 L*	
Species of fish captured (common name)	Mar. 6-19	Mar. 20-Apr. 2	Apr. 3-16
King salmon (Fork length in inches)			
1.0-1.4	2	1	
1.5-1.9		2	
2.0-2.4		1	
2.5-2.9		2	
3.0-3.4			
3.5-3.9		1	
4.0-4.4			
4.5-4.9			
5.0-5.4			
Not measured			
Totals	2	7	
Adult king salmon			
Steelhead rainbow trout	1		
Pacific lamprey			
Brook lamprey			
Ammocoete (species?)			
White sturgeon			
American shad			
Sacramento western sucker			
Carp		3	5
Sacramento blackfish			
Sacramento hitch			
Sacramento squawfish			
Splittail			
Unidentified minnows			
Channel catfish			
White catfish			
Brown bullhead			
Mosquitofish			
Striped bass			
Largemouth bass			
Green sunfish			
Bluegill			
Black crappie			
Tule perch			
Sculpin (species?)			
Tadpole		7	
Crayfish	3	2	19

* Mile and bank above Sacramento.

TABLE A-19

San Joaquin River; Banta-Carbona Irrigation District: Number of Fish Trapped in the Canal During the 1955 Irrigation Season by Two-week Periods

Species of fish captured (common name)	Mar. 20-April 2	April 3-16	April 17-30	May 1-14	May 15-28	Seasonal total
King salmon (Fork length in inches)						
1.0-1.4	13	1				14
1.5-1.9	58	22				80
2.0-2.4	19	80	18	7		124
2.5-2.9	6	95	24	13		138
3.0-3.4		27	6	2		35
3.5-3.9		1		1		2
4.0-4.4						
4.5-4.9						
5.0-5.4						
5.5-5.9						
6.0-6.4						
Not measured		1				1
Totals	96	227	48	23		394
Steelhead rainbow trout						
Pacific lamprey						
Brook lamprey						
Ammocoete (species?)		10	12			22
American shad		2				2
Smelt (species?)						
Carp				1		1
Splittail						
Unidentified minnows	7	3	2		1	13
Channel catfish						
White catfish	4	8	4	1	4	21
Brown bullhead		2				2
Mosquitofish	1		1			2
Starry flounder						
Striped bass	2	4	1	1		8
Largemouth bass						
Green sunfish	6	8				14
Warmouth						
Bluegill						
Black crappie		5	1	3		9
Tule perch						
Sculpin (species?)						
Threespine stickleback						
Tadpole	2					2
Crayfish						

TABLE A-20

San Joaquin River; El Solyo Water Company: Number of Fish Trapped in the Canal During the 1955 Irrigation Season by Two-week Periods

Species of fish captured (common name)	Mar. 20-April 2	April 3-16	April 17-30	May 1-14	May 15-28	May 29-June 11	Seasonal total
King salmon (Fork length in inches)							
1.0-1.4	14	1					15
1.5-1.9	22	15	4				21
2.0-2.4		8	27				35
2.5-2.9		1	10				11
3.0-3.4			1				1
3.5-3.9			1				1
4.0-4.4							
4.5-4.9							
5.0-5.4							
5.5-5.9							
6.0-6.4							
Not measured		1					1
Totals	36	26	43				105
Steelhead rainbow trout							
Pacific lamprey							
Brook lamprey							
Ammocoete (species?)							
American shad							
Smelt (species?)							
Carp		2	2	4	8		16
Splittail							
Unidentified minnows			2		1		3
Channel catfish							
White catfish	2	1	3		1		7
Brown bullhead							
Mosquitofish	2	5	12				19
Starry flounder							
Striped bass						1	1
Largemouth bass	1						1
Green sunfish	5	2	2		4		13
Warmouth							
Bluegill							
Black crappie			1				1
Tule perch							
Sculpin (species?)		1					1
Threespine stickleback							
Tadpole		2	1				3
Crayfish	2	2	2	1			7

TABLE A-21

San Joaquin River; Patterson Water Company: Number of Fish Trapped in the Canal During the 1955 Irrigation Season by Two-week Periods

Species of fish captured (common name)	Mar. 20-April 2	April 3-16	April 17-30	May 1-14	May 15-28	Seasonal total
King salmon (Fork length in inches)						
1.0-1.4			1			1
1.5-1.9						
2.0-2.4						
2.5-2.9	2	1		1		4
3.0-3.4	10	4				14
3.5-3.9	2					2
4.0-4.4						
4.5-4.9						
5.0-5.4						
5.5-5.9						
6.0-6.4						
Not measured						
Totals	14	5	1	1		21
Steelhead rainbow trout						
Pacific lamprey						
Brook lamprey						
Ammocoete (species?)			1			1
American shad						
Smelt (species?)						
Carp	3				1	4
Splittail	1				1	2
Unidentified minnows	9	2	1		1	13
Channel catfish						
White catfish	9	1	2	6	4	22
Brown bullhead						
Mosquitofish	1					1
Starry flounder						
Striped bass						
Largemouth bass						
Green sunfish	9				2	11
Warmouth						
Bluegill						
Black crappie		1			1	2
Tule perch						
Sculpin (species?)						
Threespine stickleback						
Tadpole		7	3	2	1	13
Crayfish	1		2	2	1	6

TABLE A-22

Sacramento-San Joaquin River Delta; East Contra Costa Irrigation District: Number of Fish Trapped in the Canal During the 1955 Irrigation Season by Two-week Periods

Species of fish captured (common name)	April 3-16	April 17-30	May 1-14	May 15-28	May 29-June 11	June 12-25	Seasonal total
King salmon (Fork length in inches)							
1.0-1.4							
1.5-1.9					2		2
2.0-2.4	1			2	2	2	7
2.5-2.9	4	4	9	24	16	10	67
3.0-3.4	2	16	16	30	23	5	92
3.5-3.9		13	2	3	3		21
4.0-4.4	1	6	1				8
4.5-4.9	2	2					4
5.0-5.4	2	3	1				6
5.5-5.9							
6.0-6.4		1					1
Not measured	2	1	12	4	3	1	23
Totals	14	46	41	63	49	18	231
Steelhead rainbow trout		1	1				2
Pacific lamprey			5				5
Brook lamprey							
Ammocoete (species?)		6		4	3		13
American shad							
Smelt (species?)	5	1			500		506
Carp		2	1	4	10		17
Splittail							
Unidentified minnows	6	1		2	3		12
Channel catfish							
White catfish	15	1	1	2	6		25
Brown bullhead							
Mosquitofish							
Starry flounder		2	2	7	8		19
Striped bass	3	1	1		2		7
Largemouth bass							
Green sunfish	10	7	4	3	10		34
Warmouth							
Bluegill							
Black crappie			1				1
Tule perch							
Sculpin (species?)	3		1	1	4		9
Threespine stickleback	1	1	1	2	2		7
Tadpole							
Crayfish	1						1

TABLE A-23

Sacramento-San Joaquin River Delta; Diversion Sampling: Number of Fish Trapped in Canals During the 1955 Irrigation Season

Species of fish captured (common name)	Contra Costa Canal Bureau of Reclamation		Reclamation District No. 501		Passaglia Brothers		Woodbridge Irrigation District			
	May 29-June 11	June 12-25	May 29-June 11	June 12-25	May 29-June 11	June 12-25	Mar. 20-Apr. 2	Apr. 3-16	Apr. 17-30	May 1-14
King salmon (Fork length in inches)										
1.0-1.4							1			
1.5-1.9										
2.0-2.4		1	4			2		2		
2.5-2.9	5	8	21	5		3				
3.0-3.4		4	12	5		3				
3.5-3.9			1		3	8				
4.0-4.4	1									
4.5-4.9										
5.0-5.4										
5.5-5.9										
6.0-6.4										
Not measured		1								
Totals	6	14	38	10	3	16	1	2		
Steelhead rainbow trout										
Pacific lamprey										
Brook lamprey					8	3				
Ammocoete (species?)							1	7	18	
American shad										
Smelt (species?)	30		10	1	6					
Carp			13		1					
Splittail										
Unidentified minnows			5	2		2				
Channel catfish					1					
White catfish		3	74	18	45	28				
Brown bullhead			5		2	1				
Mosquitofish										
Starry flounder	5									
Striped bass		4	1							
Largemouth bass										
Green sunfish		1	150	2	5	1	6	12	1	1
Warmouth						1				
Bluegill			1							
Black crappie					6					
Tule perch				1						
Sculpin (species?)	2			1						
Threespine stickleback	1									
Tadpole	2						8	1		
Crayfish			11							

TABLE A-24

Butte Creek; Diversion Sampling: Number of Fish Trapped in Canals During the 1957 Irrigation Season

Species of fish captured (common name)	Phelan-Parrott* Irrigation system					Durham Mutual Water Company, Ltd.				
	Jan. 6-19	Jan. 20-Feb. 2	Feb. 3-4	Feb. 17-Mar. 2	Seasonal total	Jan. 6-19	Jan. 20-Feb. 2	Feb. 3-16	Feb. 17-Mar. 2	Seasonal total
King salmon										
1.5-2.0 inches (fork length)		66	21		87			45	160	205
Not measured	31				31					
Totals	31	66	21		118			45	160	205
Pacific lamprey								1		1
Sacramento western sucker	1	3	1		5					
Unidentified minnows	4	45	14		63			2		2
Riffle sculpin			1		1					

* Often referred to as Parrott-Phelan.

CALIFORNIA STURGEON TAGGING STUDIES[1]

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INTRODUCTION

Heavy commercial fishing in the late 1800's depleted the populations of sturgeon in California so much that the commercial fishery was closed in 1901. In 1910 it was reopened to limited fishing, but in 1917 it was closed again. From then until 1954 no sturgeon could be taken legally.

By the early 1950's, sturgeon had again become fairly abundant. Therefore, the Fish and Game Commission opened an all-year sport fishing season on April 1, 1954. The regulations provided for a one-fish daily bag limit and a 40-inch minimum size limit.

Relatively little was known about sturgeon in California, so in July of 1954 a study to gather facts pertinent to their management was begun. Some of the facts gathered on this investigation have already been reported (Pycha, 1956), but the results of a tagging study carried out in the fall of 1954 have not. It was initiated to measure the fishing mortality rate and to gather more knowledge of migrations. Since there have been few recent tag returns from these sturgeon, little additional information may be expected, and this is the final report.

The planning and field operations of this study were carried out by Richard Pycha (op. cit.), and the author's part in the study was restricted to analyzing the tag returns.

METHODS

Totals of 994 white sturgeon (*Acipenser transmontanus*) and 25 green sturgeon (*A. medirostris*) were tagged in San Pablo Bay between early August and mid-November of 1954. These fish were caught in trammel nets. Handling and tagging methods are described by Pycha (op. cit.).

Most of the sturgeon were double-tagged, and three types of tags were used in the study. The first type was a Petersen disk tag made with cellulose nitrate disks and Type 302 soft stainless steel wire. These tags were placed on the base of the upper lobe of the caudal fin.

The second type of tag was a "spaghetti" tag similar to the Type G tags used on tuna (Wilson, 1953). It differed from the tag described by Wilson in that the sheath was red transparent Transflex tubing, and a monofilament nylon leader was threaded through the inner tubing.

[1] Submitted for publication April, 1959. This work was performed as part of Dingell-Johnson Project California F-9-R, "A Study of Sturgeon and Striped Bass," supported by federal aid to fish restoration funds.

These tags were inserted between two dorsal scutes about half way back on the body.

The third kind of tag employed was the disk-dangler tag, which is a modification of the Atkins tag (Calhoun, 1953). Cellulose nitrate disks and tantalum wire 0.032 inch in diameter were used in these tags. On some fish the tags were placed below the dorsal fin, while on other fish they were placed on the upper lobe of the caudal fin.

RESULTS

White Sturgeon

Mortality Estimates

In the $4\frac{1}{2}$ years since the 994 white sturgeon were tagged, 27 tags have been returned by anglers and 35 by commercial fishermen (Table 1). The commercial returns are from sturgeon caught incidentally in a gill net fishery for king salmon (*Oncorhynchus tshawytscha*) and American shad (*Alosa sapidissima*). Since the law required that these

TABLE 1

White Sturgeon Tag Returns

Elapsed days to recapture	Angling returns	Commercial returns	Totals
0-365	19	33	52
366-730	6	2	8
more than 730	2	0	2
Totals	27	35	62

sturgeon be returned to the water unharmed, it is not possible to assess the significance of these returns.

In calculating the rate of exploitation during the year after tagging, the sturgeon less than 40 inches long have to be omitted because the minimum size limit was 40 inches. This reduces the number of tagged fish to 888 and the first year angling returns to 18 tags. Therefore, 2 percent of the tags from legal-sized white sturgeon were returned by anglers in the year following tagging.

In order for this to be an unbiased estimate of the rate of exploitation, the tagging study must fulfill several basic conditions (Ricker, 1958), as follows: the tags must not be shed, they must not affect the vulnerability or mortality of the tagged fish, all recaptures must be reported, and the tagged fish must be a random sample of the population.

In this study the only direct measure of how well these conditions were met comes from a comparison of the returns from the various combinations of tags used (Table 2). The differences among the proportions of tag returns from the six groups are not statistically significant. This means that the combined rate of shedding, nonreturn, and tagging mortalities is approximately the same for each kind of tag. Furthermore, the rate of shedding during the first year would have to be low

TABLE 2

Comparison of White Sturgeon Tag Groups and Tag Returns

Tag group	Number tagged	Number returned	Expected return*
Petersen disk (single tag)	142	8	8.9
Spaghetti (single tag)	83	5	5.2
Petersen disk and spaghetti	536	33	33.4
Petersen disk and disk-dangler	169	12	10.5
Disk-dangler and disk-dangler	39	2	2.4
Disk-dangler and spaghetti	25	2	1.6
Totals	994	62	62

* Assuming a proportionate return from each tag group.

because it is the only factor likely to affect single- and double-tagged fish differently, and a high rate of shedding would result in greater returns from double-tagged fish than from single-tagged fish.

While there are no measures to indicate the magnitude of the deviations from the other basic conditions, these deviations would have to be of great magnitude to have a significant effect on the conclusions about angling harvest. For example, if half of the tags on fish caught by anglers were not returned, the true rate of exploitation would still only be 4 percent. Most factors that could be affecting the tag returns would result in an underestimate of the rate of exploitation, but it seems unlikely that any factor or combination of factors would make the true rate of exploitation more than four or five times that indicated by the tag returns. Therefore, the actual percentage of the white sturgeon present in San Pablo Bay during the fall of 1954 that was caught by anglers in the year following tagging probably falls between 2 and 10 percent.

The tag returns were not used to estimate the natural mortality rate because the rate of tag return decreased so sharply after the first year. It is unlikely that the actual survival in a long-lived fish like sturgeon would be as low as the sharp decrease in tag returns indicate. Therefore, the rapid decrease in tag returns probably reflects some other factor, such as emigration out of the San Francisco Bay area (see section on migrations) or a decrease in the harvest rate resulting from new angling regulations adopted in the spring of 1956. At that time the minimum size limit was increased to 50 inches, and the highly effective snagging of sturgeon by trolling was outlawed.

Migrations

Most of the tag returns from locations in the San Francisco Bay-Delta area fall into two main groups (Table 3). One group was recovered in May and September between Carquinez Strait and the confluence of the Sacramento and San Joaquin Rivers; the other, in the fall in San Pablo Bay. They represent, respectively, the returns from the commercial salmon gill net fishery and those from the most important sport fishery. Most commercial fishing was done in these months and was

TABLE 3

White Sturgeon Tag Returns By Month and Area of San Francisco Bay Region

Month of recapture	Area of recapture		
	San Pablo Bay	Carquinez Strait to confluence of Sacramento-San Joaquin Rivers	Delta above confluence of Sacramento-San Joaquin Rivers
January			
February			
March	1		1
April			
May	2	7	
June	1	1	
July		1	
August			
September	3	25	1
October	6		
November	5		1
December	1		
Totals	19	34	3

restricted to this area, and most sturgeon caught elsewhere by angling were taken accidentally by anglers fishing for striped bass (*Roccus saxatilis*). Therefore, these returns reflect the locality and season of the major fisheries rather than the true migratory pattern of white sturgeon.

While the returns did not reveal a migratory pattern in the San Francisco area, they demonstrated that sturgeon sometimes migrate considerable distances along the Pacific Coast; e.g., a white sturgeon was recaptured on August 26, 1955, at the mouth of the Columbia River, 294 days after it was tagged in San Pablo Bay. This represents a minimum distance traveled of about 660 miles.

Green Sturgeon

Three tags have been returned from the 25 green sturgeon tagged in San Pablo Bay. They are unusually interesting because they are all from Oregon. Two of the fish were taken near the mouth of the Columbia River—one on December 4, 1955, and the other on August 20, 1958. The third was recovered in Winchester Bay on September 1, 1957. These returns indicate that there is a considerable interchange among the green sturgeon populations along the Pacific Coast.

CONCLUSIONS

Two important conclusions may be drawn from the tagging results. The first is that anglers harvested only a small portion of the white sturgeon during the year after they were tagged, even though the angling regulations then were more liberal than they are now. The other conclusion is that there is an interchange among both the white and green sturgeon populations along the Pacific Coast.

SUMMARY

In 1954 a sturgeon sport fishing season was opened in California for the first time in 37 years. The Department of Fish and Game needed more facts about sturgeon to develop a sound management program. A research project was set up to get these facts, and one phase of this project was a sturgeon tagging study designed to determine the mortality rates and the migration patterns occurring in the populations.

During the fall of 1954, 994 white sturgeon and 25 green sturgeon were tagged in San Pablo Bay. Petersen disk, disk dangler, and spaghetti tags were used. Only 62 of the white sturgeon and three of the green sturgeon tags have been returned by anglers and commercial fishermen.

The angler return of white sturgeon tags indicates that between 2 and 10 percent of the white sturgeon present in San Pablo Bay during the fall of 1954 was harvested in the year following tagging.

The tag returns from localities in the San Francisco Bay and Delta area do not reveal any migratory pattern for white sturgeon. This does not mean that there is no migratory pattern, since the fishery was mostly restricted to two periods and the tag returns reflect only this.

One of the white sturgeon and all three of the green sturgeon returns were from Oregon waters, showing that there is some interchange among the sturgeon populations along the Pacific Coast.

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THE USE OF PROBABILITY SAMPLING FOR ESTIMATING ANNUAL NUMBER OF ANGLER DAYS[1]

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INTRODUCTION

Fisheries research and management investigations often require information on the size of catch and the amount of effort expended to make the catch. Such information usually is an estimate based upon samples, because complete counts are often prohibitively expensive. Methods of obtaining estimates may be divided into two broad categories—probability sampling and nonprobability or "judgement" sampling. The former includes all methods based on the theory of probability where the chance of selecting any particular unit in the population is known. In practice some mechanical randomizing process is usually used in selecting a probability sample and certain of these are thus known as random samples. In nonprobability sampling the decision as to which units enter the sample is left to an individual's judgment so that the chance of selecting a particular unit is unknown.

Most sample estimates in fisheries literature are based on nonprobability samples. Although these may give good estimates, and in some situations offer the only practical method of sampling, the precision of the estimates obtained generally cannot be determined. On the other hand, probability samples are designed so that the sampling error can be measured objectively.

In this article we illustrate the construction of a probability sampling plan for estimating the number of angler-days expended annually by persons 12 years of age and over at the Moss Landing Pier, Monterey County, California.

A sample survey involves several steps—procuring preliminary data from a census or presurvey, designing a sampling plan, and carrying out the survey. Our preliminary data consisted of an actual daily count of anglers during 1956. A sample survey, based on the best sampling plan, was not actually carried out, but a plan constructed from the 1956 angler count was tested by applying it to data from a complete 1957 angler census.

We wish to acknowledge the help of Mr. Daniel J. Miller who suggested this problem and Mr. Wilbur C. Sandholdt who graciously furnished the angler-count data.

[1] Submitted for publication February, 1959. The data were collected by Dan Miller in connection with Dingle-Johnson Project, California F-12-R, "Northern California Marine Sport Fish Survey," supported by Federal Aid to Fish Restoration funds.

DESCRIPTION OF THE SAMPLING PLANS

Three types of sampling plans were considered and applied to the Moss Landing data. These were: simple random sampling, stratified random sampling with proportional allocation, and stratified random sampling with optimum allocation. The days of the year constituted the sampling units under each of these plans. In practice the days to be enumerated must be randomly selected before the year begins. The most convenient method of drawing a random sample is by using a table of random numbers. A lucid description of the use of such a table is found in Dixon and Massey (1957).

The notation and formulas used herein are from Cochran (1953).

Simple Random Sampling

Under simple random sampling the days of the year were considered a single, undivided population.

The notation and formulas used are:

N	Number of days in year
n	Number of days in sample
y_i	Number of anglers fishing on ith day ($i = 1, 2, \ldots N$)
Y	Total number of angler days in year
$\hat{Y}$	Estimate of Y from sample
y	Total number of angler days in sample

$$\overline{Y} = \frac{\sum_{i=1}^{N} y_i}{N}$$ Population mean

$$S^2 = \frac{\sum_{i=1}^{N} (y_i - \overline{Y})^2}{N - 1}$$ Population variance

Y is estimated from a sample by

$$\hat{Y} = \frac{Ny}{n}$$

and the variance of this estimate is

$$V(\hat{Y}) = \frac{N^2 S^2}{n} \frac{(N - n)}{N}.$$

When the $\overline{Y}$ and S^2, or sample estimates of them, are available, the sample size required to estimate Y with a confidence interval of a desired width and probability level can be determined. The sample size is determined from

$$n = \frac{N^2 S^2}{V + NS^2}$$

where

$$V = \frac{d^2}{z^2_{1/2\alpha}}$$

d Width of one-half the desired confidence interval

$z_{1/2\alpha}$ Standardized normal variate at the $\frac{1}{2}\alpha$ probability level.

It is assumed throughout that the estimates are normally distributed and the variances either known or well determined so that z may be taken from a table of the normal distribution.

Stratified Sampling

Stratified sampling can be used when a population is divisible into non-overlapping subpopulations or strata. It is a more efficient method than simple random sampling if the subpopulations are internally homogeneous with respect to the characteristic being observed. When using stratified sampling, the samples must be selected randomly from each stratum rather than from the population as a whole.

For the purpose of sampling at the Moss Landing Pier the year was divided into winter and summer strata.

Winter Strata

January through May, October through December

I Mondays and Fridays following holidays, and Saturdays.
II Sundays and holidays.
III Weekdays not included above.

Summer Strata

June through September

IV Mondays and Fridays following holidays, and Saturdays.
V Sundays and holidays.
VI Weekdays not included above.

The six strata were so defined because examination of several years' data seemed to indicate that within such divisions the angler count would be uniform.

The notation and formulas for stratified sampling are:

$N = N_1 + N_2 + \ldots + N_L$	Number of days in year which is the sum of the days in the L strata.
N_h	Number of days in hth stratum ($h = 1, 2, \ldots L$)
$n = n_1 + n_2 + \ldots + n_L$	Number of days in total sample which is the sum of the days in the L strata samples.
n_h	Number of days in sample from hth stratum
y_{hi}	Number of anglers fishing on ith day of the hth stratum ($i = 1, 2, \ldots N_h$)

$$\overline{Y}_h = \frac{\sum_{i=1}^{N_h} y_{hi}}{N_h}$$ True mean number of anglers of hth stratum

$$\overline{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$$ Sample mean number of anglers of hth stratum

$$S_h^2 = \frac{\sum_{i=1}^{N_h} (y_{hi} - \overline{Y}_h)^2}{N_h - 1}$$ True variance of hth stratum.

The estimate of Y from a stratified sample is

$$\hat{Y}_{st} = \sum_{h=1}^{L} N_h \overline{y}_h$$

and the variance of this estimate is

$$V(\hat{Y}_{st}) = \sum_{h=1}^{L} N_h(N_h - n_h) \frac{S_h^2}{n_h} .$$

The size of the variance of the estimate depends upon the allocation of the sample to the strata as well as on the sizes of the true strata variances. Two types of allocation were considered—proportional and optimum.

Under *proportional allocation* the sample size required to obtain a predetermined confidence interval is

$$n = \frac{N\sum_{h=1}^{L} N_h S_h^2}{V + \sum_{h=1}^{L} N_h S_h^2}$$

with V defined as under simple random sampling. The sample is allocated in proportion to strata sizes, so that the strata sample sizes are $n_h = nN_h/N$. Ordinarily, for a given sample size, proportional allocation can be expected to provide an estimate of Y which has a variance as small as or smaller than that which would be obtained under simple random sampling.

Under optimum allocation the sample is allocated so that each stratum sample size is proportional to the product of the stratum size and stratum standard deviation. The sample size for a predetermined confidence interval is

$$n = \frac{\left(\sum_{h=1}^{L} N_h S_h\right)^2}{V + \sum_{h=1}^{L} N_h S_h^2}$$

where V is again defined as under simple random sampling. The strata sample sizes are obtained from

$$n_h = \frac{nN_h S_h}{\sum_{h=1}^{L} N_h S_h}.$$

For fixed n, optimum allocation will yield an estimate of Y with a variance less than or equal to that obtainable under either proportional allocation or simple random sampling. However, to obtain the precision offered by an optimum allocation plan it is necessary to predict or estimate accurately the strata variances of the population being sampled. If grossly inaccurate estimates of the variances are used in designing the sampling plan, the variance of the estimate may be even greater than that from simple random sampling.

RESULTS OF APPLYING THE SAMPLING PLANS TO THE MOSS LANDING DATA

Sample Sizes

We compared the three sampling plans by applying them to the 1956 Moss Landing data and determining the sample size required under each plan to estimate Y with a predetermined confidence interval. A confidence interval with a half-width of 5687.4, or 15 percent of the total angler days, and a probability level of .95, was chosen to compare the sampling plans.

The sample sizes needed to obtain Y with the given confidence interval were computed from the formulas in the preceding sections using population parameters shown in Table 1. The required sample sizes under optimum allocation, proportional allocation, and simple random sampling, respectively, were 39.1, 54.0, and 100.9 (Table 2). In this case, the optimum allocation plan requires considerably less sampling effort than does either simple random sampling or proportional allocation. Because sampling is most efficient with optimum allocation and would cost no more than with the other methods, it seemed the best plan to use here.

It should be noted that under stratified sampling plans the strata sample sizes (Table 2) must be rounded to integers for actual sampling purposes; therefore, the exact optimum or proportional allocations will not be achieved in practice. This results in some loss of the precision predicted by the sampling plans. When the strata sample sizes were rounded to integers, the half-width of the 95 percent confidence interval for the 1956 optimum allocation sample of 39 was 5705.1 or 15.05 percent of the total effort. The loss in precision due to rounding was negligible.

Suitability of 1956 Optimum Allocation Plan for Sampling in 1957

For a problem of this type where the sampling units are units of time, it is necessary to base the sampling plan on data from a period prior to that from which the sample is drawn. If the population parameters for the period being sampled differ from those for the period upon which the sampling plan was based, the precision predicted by the sampling plan will not be achieved. Under our optimum allocation plan, both the strata sizes and the strata variances can be expected to change somewhat from year to year. Both of these factors will affect the variance of the estimated total.

To examine the results of applying the 1956 optimum allocation plan in 1957, we computed the 95 percent confidence interval from the 1957 data (Table 1) using the strata sample sizes determined for 1956. The strata sample sizes were rounded to the nearest integer before computations were made. The confidence interval half-width, d, was computed from

$$d = z_{.025}\sqrt{V(Y)_{st}}.$$

The resulting half-width was 3071, or 13.5 percent of the 1957 Y. The 1956 design proved suitable for a 1957 sampling program insofar as the 1957 confidence interval was within the limits set for the 1956 plan.

The effect population changes between 1956 and 1957 had upon the allocation was determined by computing the optimum allocation of a sample of 39.1 based on the 1957 strata sizes and strata variances (Table 3). The actual optimum allocation for 1957 differed little from the strata sample sizes indicated by the 1956 optimum allocation plan. In fact, after rounding the sample sizes to the nearest integer the 1956 and 1957 allocations were identical with the exception of the sample from Stratum VI. Here the actual 1957 allocation called for a sample of 14 as opposed to 13 under the 1956 plan.

If the relative magnitudes of the products of individual strata sizes and their standard deviations are generally as stable as they were between 1956 and 1957, stratified sampling with optimum allocation would be preferred. The plan for a particular year's sampling then could be based on the results of the prior year's sample survey. The problem of over- or under-sampling for a desired confidence interval, due to general changes in the variances over all strata, would still remain. These general changes probably correspond to changes in the total angler days. If such is the case, the sample size may be increased or decreased according as it is suspected that the total angler days will increase or decrease. This procedure should correct, in part at least, the problem of over- or under-sampling.

TABLE 1

Population Parameters for Moss Landing, 1956-57

Stratified

Stratum	Number of days N_h	Stratum variance S_h^2	Stratum standard deviation S_h	Mean angler days $\bar{Y}_h$	Total angler days $N_h\bar{Y}_h$
1956					
I	38	1,824.481	42.713	91.289	3,469
II	40	5,804.667	76.188	135.000	5,400
III	166	550.938	23.472	43.373	7,200
IV	19	13,210.702	114.938	223.579	4,248
V	20	16,382.450	127.994	297.150	5,943
VI	83	5,856.980	76.531	140.434	11,656
1957					
I	35	591.375	24.318	54.543	1,909
II	42	1,361.454	36.898	76.095	3,196
III	166	168.032	12.963	28.229	4,686
IV	19	3,243.433	56.951	120.895	2,297
V	21	3,538.048	59.481	170.619	3,583
VI	82	2,003.562	44.761	85.761	7,029

Unstratified

Year	Number of days N	Variance S^2	Standard deviation S	Mean angler days $\bar{Y}$	Total angler days Y
1956	366	8,758.263	93.585	103.595	37,916
1957	365	2,622.194	51.207	62.192	22,700

TABLE 2

Allocation of Samples for .15Y, 95 Percent Confidence Intervals
(Half-width 5687.4)

Moss Landing, 1956

Stratum	Stratum size	Optimum allocation	Proportional allocation	Simple random sample
I	38	3.2	5.6	
II	40	6.1	5.9	
III	166	7.8	24.5	
IV	19	4.3	2.8	
V	20	5.1	3.0	
VI	83	12.6	12.2	
Totals	366	39.1	54.0	100.9

TABLE 3

Optimum Allocation of Sample Required for .15Y, 95 Percent Confidence Interval in 1956
Compared With the True Optimum Allocation of the Same Sample Size in 1957

Moss Landing

Stratum	1956 allocation	1957 allocation	$\frac{n_{h,1956}}{n}$	$\frac{n_{h,1967}}{n}$
I	3.2	3.2	.082	.082
II	6.1	5.7	.156	.146
III	7.8	8.0	.199	.205
IV	4.3	4.0	.110	.102
V	5.1	4.6	.130	.118
VI	12.6	13.6	.322	.348
n	39.1	39.1		

SUMMARY

The advantages of probability sampling over nonprobability sampling are discussed.

Simple random sampling, stratified random sampling with proportional allocation, and stratified random sampling with optimum allocation are considered as methods for estimating the annual number of angler days expended at the Moss Landing Pier.

Sample sizes for estimating total angler days with a 95 percent confidence interval having a half-width equal to 15 percent of the total were determined for each of the three sampling methods.

The required sample sizes for simple random sampling, proportional allocation, and optimum allocation were 100.9, 54.0, and 39.1, respectively.

The 1956 optimum allocation plan when applied to the 1957 angler count data was found suitable for estimating the number of angler days.

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AN ECOLOGICAL STUDY OF THE FOOD HABITS OF THE MOURNING DOVE[1]

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INTRODUCTION

In California the mourning dove, *Zenaidura macroura* has become the number one game bird species. In 1958 the postal survey estimated the harvest at 3,399,000 doves, and approximately 184,000 hunters entered the field in pursuit of this fast flying and elusive bird (Game Take Hunter Questionnaire, 1958). Although much is known about this important game species, a search through the literature reveals very few contributions to the fundamental life history knowledge of the mourning dove in California, and almost nothing of its food habits.

Other states have found the need to study the feeding habits of the dove; even in those states, such as Iowa, which have no open season on the dove. McClure (1943) carried out an excellent ecological study of the dove in Iowa, and Korschgen (1955) reported on the food habits of the Missouri dove. Most of the other work has been done in the southeastern United States: Rosene (1939) in Alabama; Cummings and Quay (1953) in North Carolina; Murry (1952) in Louisiana; and Kappen's (1938) general report covering several of the southeastern states.

In order to fulfill this need to obtain more information about the mourning dove, a study was initiated in 1956. Its purpose was to add to the knowledge of the life history and habits of the mourning dove in California, information which might prove useful not only to the game manager, but also to the sportsman and the non-hunting public. Five areas in California, under intensive nesting and banding study by the Upland Game Investigations personnel (P-R Project W-47R), were selected as sample sites for a statewide food habits determination.

One of these five study areas is located in the southern part of the Sacramento Valley and is situated directly east of the Mather Air Force Base, about 15 miles east of the City of Sacramento. This "Mather Field Study Area" typifies much of that region that lies on the east side of the Great Central Valley adjacent to the Sierra Nevada Mountains. Because of its accessibility it offered the valuable opportunity to make a local and intensified ecological food habits study which is reported herein.

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Special acknowledgment is given to Howard R. Leach for direction, supervision, editing and aid in gathering field data, photographs, and dove crops for this study.

THE STUDY AREA

General Description

The Mather Field dove study area consists of a 40 acre abandoned almond and olive orchard, surrounded and isolated by cultivated and fallow fields and rangeland. The site is typical of the lower terrace section of the valley-foothill grasslands area of California, i.e., that section between the lower foothills and the valley proper. This region is characterized by iron hardpan soils of low agricultural value, furnishing for the most part only dry rangeland or pasturage and some dry cereal grain farming. This general region is further characterized by the stand of plants it supports, known as the "California annual type." This herbaceous cover which carpets about 25,000,000 acres of California rangeland constitutes the vegetation of extensive valley and foothill areas and forms the ground cover under the more open woodlands and chapparal as well. Introduced or alien plant species, most of which have come from the Mediterranean, comprise an average of about 60-80 percent of the composition of this singular type (Heady, 1956; Talbot, *et al*, 1939). These annual plants normally germinate in the fall, winter, and early spring months and mature by summer. Wide fluctuations occur from year to year in their growth and relative abundance, as affected by the length of the growing season and amount of rainfall (15-35 inches a year).

Vegetative Composition

In order to record the vegetation composition and phenological succession of plants, it was deemed necessary to delineate the principal physiographical components of the area. Resolved were six vegetative units and their respective plant communities, namely, orchard, cultivated field, fallow field, rangeland, vernal pool, and roadside. Figure 1 is an aerial photograph of the study area showing the orchard and surrounding fields.

Two plots, similar to those employed in a point-transect method of evaluating vegetative percentage composition (Coupland, 1950), were placed at random in each of the physiographic types. A yard-long frame divided into 10 points was placed in four compass positions from a plot marking stake. From January through August, 1958, at intervals of one to two weeks, recordings were made of the plant species touched. Because of the scope and time element involved in this study, this method was used not as a quantitative measure of the composition, but rather as a means of determining the species, the relative abundance of the species, and the seasonal succession of the plants growing

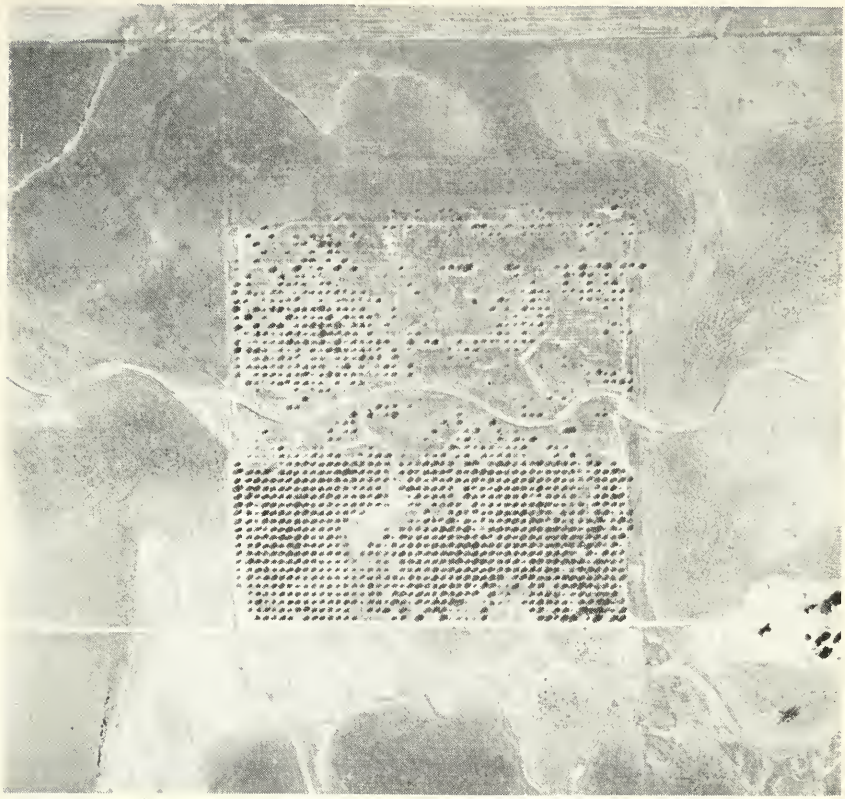

FIGURE 1. Aerial photograph showing the orchard and the surrounding fields. The vernal pool depressions may be seen below the orchard. *(Photograph by Al Reese)*

on the study area. This self-disciplinary method, together with extensive field notes yielded enough data with which to present an adequate plant description of the study site. A check list of the 107 plants species identified and their families and relative abundance in the physiographic units will be found appended to this paper (Table A-1). The scientific names for the individual species may be found in the appended check list; only the common names will be used in the text.

The following is a vegetative description of the physiographical units:

Orchard

Half of the abandoned orchard in which the doves nest is planted in olive trees. The other half, separated by a small intermittent watercourse, is composed of almond trees. The trees are neglected and some are in a decadent condition. The understory during the spring months of the year is composed predominantly of the annual grasses—soft chess, ripgut, red brome, silver hairgrass, wild oats, and fescue; and the broad-leaved herbs—broad-leaf filaree, bur clover, hillside lotus, bedstraw and chickweed. During 1958 these spring annuals started to

flower about the middle of April and matured the first week of May. After they had gone to seed and started to dry, the summer annuals such as sheep sorrel, tarweed, vinegar weed, and turkey mullein were beginning to assert themselves in the vegetative composition. These late annuals occurred mostly in the open areas of the almond orchard where the trees are scattered and furnish less overstory. Where the trees are in close rows in the olive orchard, soft chess remained the dominant species throughout the spring and in the opened areas, until it matured and dried up, filaree was the dominant cover plant.

Cultivated Fields

The local agricultural practice is rotation of winter cereal crops. The grain is planted in the fall or early winter and matures by the end of May. The grain is allowed to dry in the field for a month and then harvested about the end of June.

During the study period oats and wheat were grown. The most abundant weeds found growing in the grain were red maids, broadleaf filaree, smooth cats-ear, toad rush, and windmill pink. Scattered stands of wild radish and mustard were present also. Red maids and filaree mature and go to seed by mid-April, windmill pink and smooth cats-ear by the middle of May. By harvest time all of the spring annuals are dry and the summer annuals, such as turkey mullein, tarweed, vinegar weed, and yellow star thistle appear and go to seed later in the summer.

Fallow Field

After the grain is harvested in the summer the fields normally are untouched until the following spring when the stubble is burned and the fields plowed under for summer fallow. After the fall rains there is a sparse growth of volunteer grain and broadleaf filaree plants and annual grasses. Later weedy annuals appear in the form of red maids, mouse-eared chickweed, toad rush, and windmill pink. The growth pattern is the same as that found in the cultivated fields with the early spring annuals maturing in April and May, and the summer annuals, such as sheep sorrel, vinegar weed, tarweed, turkey mullein and valley spurge maturing in midsummer. The annuals found in the fallow fields generally are of a robust nature, probably because of a lack of competition with other plants.

On a field left untilled two years the plant succession was observed to progress toward the more permanent grassland type characterized by the familiar dominant species of the rangeland areas described below.

Rangeland

Wherever the land is untillable, or untilled, such as the unused fields about the air force base and the extensive open rangeland found to the east of the study area, an annual-type grassland predominates.

In addition to the typical association of soft chess, ripgut, red brome, wild oats, and broadleaf filaree there is a scattering of sheep sorrel, darnel, quaking grass, goatgrass, and smooth cats-ear. When the grassland association dries the summer annuals, turkey mullein, vinegar weed and tarweed become evident.

FIGURE 2. A field northeast of the orchard illustrating a fallow field on April 21, 1958. The interspersal of open ground and annual vegetation, particularly early seeding red maids plants, makes an attractive feeding area. *(Photograph by Howard Leach.)*

FIGURE 3. This depicts the same field as Figure 2, but on April 9, 1959. It shows the edge of the field after it had been planted to oats. The flowering plants in the foreground are red maids. *(Photograph by Howard Leach.)*

Vernal Pool

The runoff from the fall and winter rains accumulates in most of the shallow depressions of the field and orchard areas and vernal pools are formed. Obviously the length of time that these vernal areas contain standing water varies from year to year. During the study period these depressions become ponded in February and dried up around the end of April.

Vernal pools support a dense population of specialized plants whose characteristics limit them to their short-lived habitat. The features needed by these plants to adapt to their precarious existence are described by Purer (1939) in a study made on the vernal pools found in San Diego County. It is noteworthy that the representatives of this unique plant community apparently have as cosmopolitan a distribution as does this type of vernal pool.

There is a definite succession of plants as the water evaporates. Several emergents appear while standing water remains. Spikerush hairgrass, Carter's buttercup, flowering quillwort, and grass poly emerge and as the pool begins to dry these plants mature and others appear, such as scorpion weed, dowingia, white flowered navarretia, gold fields, clover and tidy-tips. In turn, they germinate, grow rapidly and by the end of April flower in beautiful profusion. As this latter group of plants dessicate and go to seed the now dry pool bottoms soon become dominated by a small aromatic member of the mint family called Douglas' pogogyne. At the same time coyote thistle has germinated and succeeds the pogogyne as the last dominant in the vernal pool plant succession.

Roadside

The shoulders and embankments of the roads present another interesting group of plants. Many of the plants found in the other physiographic areas are found along the roadsides, but here they exhibit a somewhat different habit of growth, dominancy and plant succession. This difference stems from the varied soil-moisture conditions caused by drainage characteristic of the roadbeds and roadside ditches, as well as by the mechanical disturbance of the soil caused by road grading practices.

Some plants appear to be quite characteristic of the roadside plant association. These include darnel, hillside lotus, frying-pan poppies, common madia, meadow foam, fringe-pod, and several species of owl's clover, allocarya and brodiaea. Occasional stands of California poppy, buckthorn weed, vetch, gum plant and Bermuda grass also occur along the roadsides.

THE DOVE

There are a few resident mourning doves observed all year on the Mather Field study area. However, there is a heavy influx of birds into the area between the first of April and the first of May. The orchard, isolated and undisturbed as it is, furnishes an attractive nesting habitat and a good concentration of doves remain throughout the nesting season.

Upon arrival some of the doves immediately begin to nest. The record of the earliest active nest is April 10. The actual number of nests in

the orchard varies from year to year. The personnel of the Upland Game Project recorded 204 active nests in 1957 and 97 in 1958; and at the time of the termination of the study in June 1959, a surprising 398 active nests had been observed. They reported that the peak of nesting activity occurred between June 17th and 21st in 1957; on June 11th in 1958; and around June 12, 1959. The record of the latest active nest in the orchard is August 31st.

With the advent of the hunting season or the first cold, early fall weather there is a general emigration from the study area. Between the hunting loss and the effect of this dispersal very few dove remain about the area by the end of September.

THE FOOD HABITS

Collection

During the course of the study 275 dove crops were collected for analysis. They were collected on a monthly basis from the time the birds first arrived on the area until they dispersed with the advent of the September hunting season. Ninety-nine of the crops were taken from hunter-killed birds and the contents of 70 were obtained by flushing the crops of nestling birds with water. The remainder were collected at random in the study area by shooting.

The method used to sample the food habits of the nestling birds has been described by Macgregor (1958). This technique consists of flooding the crop with water and flushing the contents into a piece of cheesecloth (Figure 4).

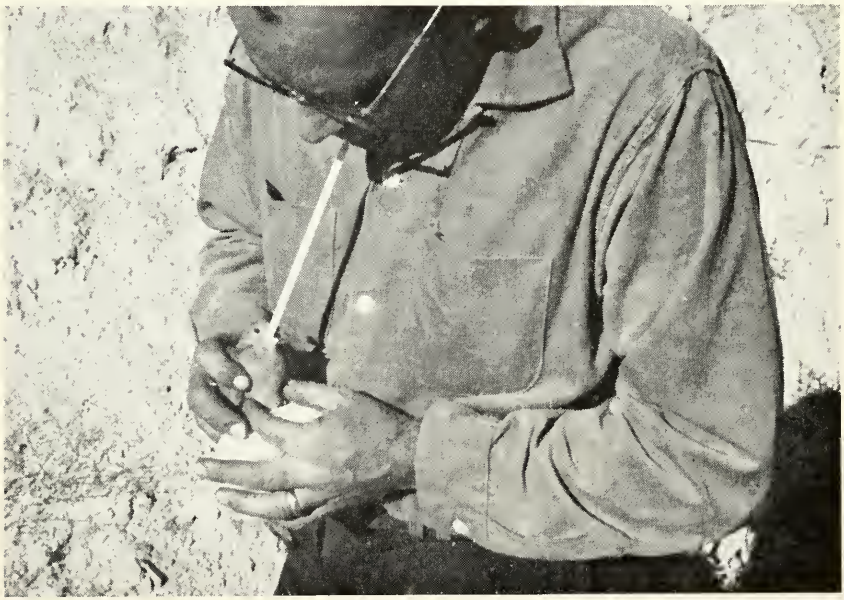

FIGURE 4. A simple method of obtaining a food habits sample without injury to the bird. *(Photograph by Howard Leach.)*

No significant difference was found in the food items of the crops from nestlings compared with those from adult birds. McClure (1943) also found this to be true in a similar comparison made in his Iowa study. For the purpose of the study the food items identified from the nestlings are considered representative of the diet of the adult nesting birds.

Method of Analysis

In the laboratory the contents of each crop was emptied into a Petri dish, oven-dried, an an analysis made by separating and identifying the food items by use of a dissecting microscope. The quantity of each item was measured in a graduated cylinder to determine the percentage composition of the entire crop content. The data were summarized by use of the aggregate percentage method described by Martin, Gensch, and Brown (1946).

Discussion of Food Items

Tables 1 and 2 give the volume percent and frequency of occurrence in percent of the food items identified in the 275 mourning dove crops examined from the Mather Field study area.

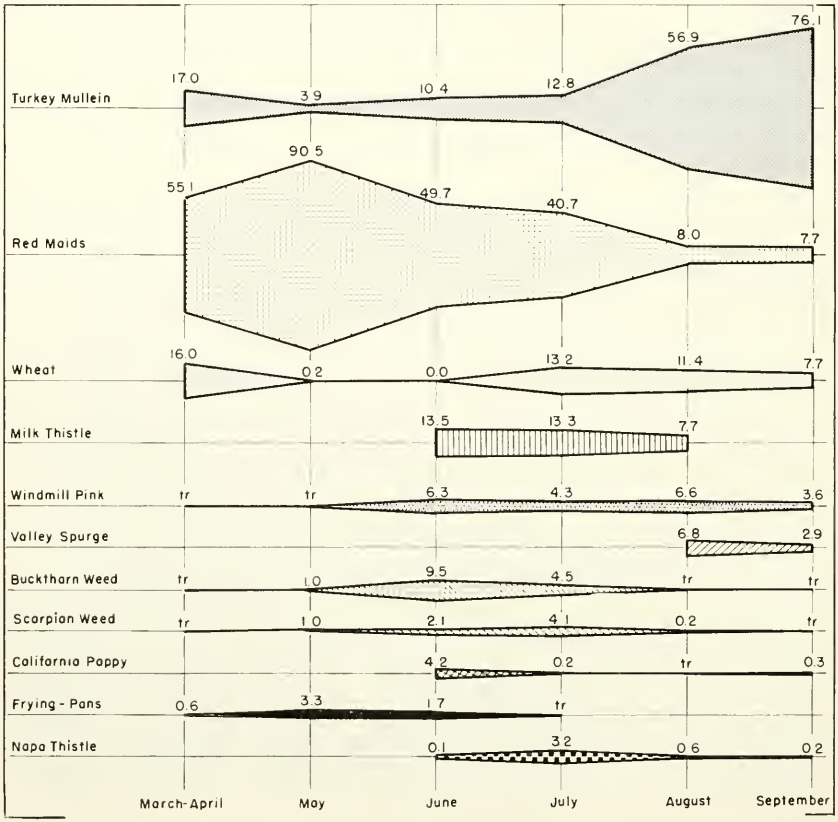

FIGURE 5. A graphical representation of the diet of the mourning dove at the Mather Field dove study area. It shows the seasonal utilization of the important food items.

Seventy-eight food items were identified. These included the seeds of 71 species of plants which made up 99.6 percent of the total diet, five items of animal food accounting for the remaining 0.4 percent. However, of these 71 plants utilized by the dove, the seeds of only 11 species contributed over 97 percent of the total volume of food found in the crops.

The two most valuable food items to the Mather Field dove proved to be the seeds of red maids and turkey mullein. Whereas the red maids plant contributed the bulk of the spring and early summer diet, turkey mullein dominated the late summer foods. In total volume these two plants made up 74.3 percent of the food eaten and occurred in over 63 percent of the crops examined.

Figure 5 is a graphical representation of the diet of the mourning dove on the study area. It conveys the monthly utilization of the preferred food items during the period of the study. The following discussion will give the contribution of these 11 food plants to the diet, when they are utilized, and where they are located on the study area. These are some of the essential factors in the consideration of the ecology of the mourning dove.

Plant Food Items

Red maids is the most important plant on the Mather Field study area. Its seeds contributed 31.5 percent of the total volume of food eaten and occurred in 66.2 percent of all the crops collected. More significant is the fact that red maids is one of the earliest spring annuals to go to seed. It seems more than coincidental that the doves arrive on the area at the same time that this annual matures. Fifty-five percent by volume of the seeds eaten by the birds collected in March and April were red maids seeds. In May they made up 90.5 percent of the food and occurred in 100 percent of the crops. In June and July the late spring annuals matured and were being utilized, but red maids seeds continued to occur in over 90 percent of the crops and constituted slightly less than 50 percent of the food eaten. In August and September when turkey mullein and the other summer annuals became available red maids seeds persisted in 61.3 percent and in 34.3 percent of the crops taken during these respective months.

The red maids plants germinate, flower, go to seed, shrivel up and disappear all in the period of two to three months. The numerous seeds are borne in a dehiscent capsule, which upon drying, literally casts out its seed. Long after the plant matures the small black seeds can be found by the thousands on the surface of the ground. Red maids are quite abundant in the cultivated and fallow fields. Before the fallow fields were plowed, the majority of the doves on the area were observed feeding there.

By the end of May and the beginning of June the "late spring annuals" mature and start to appear in the doves' diet. Three of these, frying-pan poppy, buckthorn and scorpion weeds contributed 3.4 percent of the total food eaten. Together they made up 4.3 percent of the May diet and 13.3 percent in June. Buckthorn and scorpion weeds, both members of the borage family, continued to be utilized in July (8.6 percent).

Frying-pan poppy and buckthorn weed, during favorable years, are found growing along the roadsides and borders of the fallow fields, sometimes in extensive stands. Scorpion weed, on the other hand, is an important member of the succession of plants in the vernal pool plant association and as the pools dry up may be found in solid stands in this habitat.

As the late spring herbs are drying up another crop of annuals is beginning to mature. During June and into July and August these "early summer annuals" contribute significantly to the doves' diet; especially milk thistle, windmill pink, California poppy, and Napa thistle. Although they furnished a little less than 10 percent of the total food eaten, together they contributed almost one-quarter of the food eaten in June, somewhat less in July (21.0 percent) and 14.9 percent in August.

Milk thistle plants occurred in dense stands about the three abandoned homesteads adjacent to the orchard. When these thistle patches went to seed they proved to be attractive feeding areas.

California poppies and Napa thistle occurred in scattered locations in some of the fallow fields and were less utilized.

Windmill pink deserves special mention. Although it made up only 3.8 percent of the total food eaten, its seeds were found in 55.0 percent of all the crops and in as many as 81.8 percent of those obtained in July. Windmill pink seeds can be observed by the thousands on the surface of the ground commonly mixed with those of red maids in the grain and fallow fields.

Wheat, although comprising only 7.8 percent of the diet and occurring in 18.9 percent of the crops, is considered more of a preferred food than is shown by Table 1. From field observations it was obvious that when the wheat was harvested, generally in July, these fields became attractive feeding areas. It was at this time that wheat began to appear in the dove crops in appreciable volume. A good stand of wheat about one-half mile from the orchard was burned by a wild fire and the doves flocked in by the hundreds to feed on the scorched wheat that littered the ground. If more than four doves had been collected from this feeding site the preponderance of wheat in the total diet would have been higher.

Wheat seeds also were found in the crops examined from the March-April collection. Some waste grain is always present, either left standing in unharvested patches or lying on the ground, and the dove is able to seek out and utilize this grain. A sample of five birds from an early concentration of doves collected the end of March, 1957 from one of these unharvested patches, accounted for several crops found full of wheat.

Cultivated oats is the other of the two principal grains in the study area. It was more extensively grown than wheat. Obviously it is an unimportant dove food on the Mather Field study area as it occurred in less than 1 percent of the crops examined.

While red maids was the heaviest contributor during the spring months of the study, turkey mullein dominated the diet during the summer months. It composed 42.8 percent of the total food intake and occurred in 63.0 percent of the crops. Its seeds made up over half of the

TABLE 1

Principal Food Items Eaten by 275 Mourning Dove Collected Monthly from the Mather Field Study Area, Sacramento County, 1957-59 *

	March-April		May		June		July		August		September		Total	
No. of samples	25	26	32	32	35	41	31	33	44	44	99	99	266	275
Item	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.
Plant Foods:														
Turkey mullein *Eremocarpus setigerous*	17.0	30.7	3.9	21.8	10.4	21.9	12.8	45.4	56.9	88.6	76.1	95.9	42.8	63.0
Red maids *Calandrinia caulescens*	55.1	76.9	90.5	100.0	49.7	95.1	40.7	90.9	8.0	61.3	7.7	34.3	31.5	66.2
Wheat *Triticum aestivum*	16.0	15.3	0.2	3.1	--	--	13.2	33.3	11.4	29.5	7.7	23.2	7.8	18.9
Milk Thistle *Silybum marianum*	--	--	--	--	13.5	15.3	13.3	36.3	7.7	13.6	--	--	4.6	8.7
Windmill pink *Silene gallica*	Trace	19.2	Trace	34.3	6.3	78.0	1.3	81.8	6.6	68.1	3.6	46.4	3.8	55.0
Valley spurge *Euphorbia ocellata*	--	--	--	--	--	--	--	--	6.8	34.0	2.9	33.3	2.2	17.5
Buckthorn weed *Amsinckia douglasiana*	Trace	7.6	1.0	9.3	9.5	24.3	4.5	9.0	Trace	6.8	Trace	2.0	1.9	8.4
Scorpion weed *Allocarya stipitata*	Trace	11.5	1.0	31.2	2.1	48.7	4.1	42.4	0.2	9.0	Trace	2.0	0.9	19.3
California poppy *Eschscholtzia californica*	--	--	--	--	4.2	24.3	0.2	9.0	Trace	6.8	0.3	1.0	0.7	6.2
Frying-pans *Eschscholtzia lobbii*	0.6	3.8	3.3	28.1	1.7	29.2	Trace	9.0	--	--	Trace	1.0	0.7	9.5
Napa thistle *Centaurea melitensis*	--	--	--	--	0.1	9.7	3.2	21.2	0.6	18.1	0.2	5.0	0.5	8.7
Wire grass *Polygonum aviculare*	--	--	Trace	6.2	--	--	0.3	6.0	Trace	2.2	1.1	13.1	0.4	6.6
Chickweed *Stellaria media*	4.2	23.0	Trace	6.2	0.3	12.1	Trace	9.0	Trace	4.5	Trace	1.0	0.4	6.9
Broad-leaf filaree *Erodium botrys*	0.6	3.8	Trace	9.3	0.6	15.3	0.6	6.0	Trace	6.8	Trace	5.0	0.2	7.3
Canary grass *Phalaris minor*	--	--	Trace	6.2	Trace	4.8	0.7	21.2	0.5	9.0	0.1	2.0	0.2	6.2
Vetch *Vicia americana*	1.9	3.8	Trace	3.1	Trace	2.4	--	--	Trace	2.2	Trace	2.0	0.2	2.2
Cursed crowsfoot *Geranium dissectum*	--	--	--	--	--	--	0.5	6.0	0.6	9.0	0.1	3.0	0.2	3.3
Mustard *Brassica campestris*	1.0	3.8	Trace	3.1	0.1	26.8	0.5	12.1	Trace	9.0	Trace	2.0	0.2	8.4
Hill lotus *Lotus humistratus*	--	--	Trace	6.2	--	--	Trace	12.1	0.4	22.7	Trace	4.0	0.1	7.3
Brodiaea tubers *Brodiaea* spp.	--	--	--	--	0.6	2.4	Trace	9.0	--	--	Trace	3.0	0.1	2.5
Rough pigweed *Amaranthus retroflexus*	--	--	Trace	3.1	Trace	2.4	0.3	21.2	0.1	20.4	Trace	6.0	0.1	8.7
Vinegar weed *Trichostema lanceolatum*	0.6	3.8	--	--	Trace	2.4	--	--	--	--	Trace	1.0	0.1	1.1
Chufa tubers & seeds *Cyperus esculentus*	0.4	7.6	--	--	--	--	--	--	--	--	--	--	Trace	0.7
Corn spurrey *Spergula arvensis*	Trace	11.5	Trace	19.2	0.3	9.7	Trace	9.0	Trace	4.5	--	--	Trace	6.2
Darnel *Lolium temulentum*	Trace	3.8	Trace	--	--	--	Trace	3.0	Trace	20.4	0.1	3.0	Trace	6.9
Popcorn flower *Plagiobothrys campestris*	--	--	--	--	--	--	--	--	--	--	0.1	4.0	Trace	1.5
Blue grass *Poa annua*	0.2	7.6	Trace	6.2	--	--	Trace	3.0	Trace	2.2	Trace	1.0	Trace	2.5
Quaking grass *Briza minor*	--	--	--	--	--	--	--	--	0.1	2.2	--	--	Trace	0.4
Water grass *Echinochloa crusgalli*	0.1	19.2	--	--	--	--	--	--	Trace	4.5	--	--	Trace	2.5
Lambs quarter *Chenopodium album*	--	--	Trace	3.1	--	--	--	--	Trace	2.2	Trace	2.0	Trace	1.5
Animal Foods:														
Snails Gastropoda	0.3	3.8	0.1	18.7	0.6	26.8	0.8	15.1	0.1	11.3	--	--	0.2	10.2
Bone fragments	2.0	7.6	Trace	9.3	--	--	Trace	12.1	--	--	--	--	0.2	3.3

* The principal food items considered are those which comprise 0.1 percent or more of the total volume of food eaten any one month and are expressed both in volume percent and frequency of occurrence in percent.

TABLE 2

Supplemental List of Food Items Eaten by 275 Mourning Dove Collected Monthly from the Mather Field Study Area, Sacramento County, 1957-1959 *

	March-April		May		June		July		August		September		Total	
No. of samples	25	26	32	32	35	41	31	33	41	44	99	99	266	275
Item	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.	Vol.	Freq.
Plant Foods:														
Pill-wort *Pilularia americana*	Trace	3.8	--	--	--	--	--	--	--	--	--	--	Trace	0.4
Slender pondweed *Potamogeton pusillus*	--	--	--	--	--	--	Trace	3.0	--	--	--	--	--	0.4
Grass stubble & leafage Gramineae	Trace	11.5	Trace	3.1	Trace	7.3	--	--	--	--	--	--	Trace	2.5
Bentgrass *Agrostis avenacea*	Trace	--	--	--	Trace	4.8	--	--	--	--	--	--	Trace	0.7
Silver hairgrass *Aira caryophyllea*	Trace	--	--	--	Trace	7.3	Trace	3.0	--	--	--	--	Trace	1.5
Cultivated oats *Avena sativa*	--	--	Trace	3.1	--	--	--	--	--	--	Trace	1.0	Trace	0.7
Soft chess *Bromus mollis*	--	--	Trace	3.1	Trace	2.4	Trace	3.0	--	--	--	--	Trace	1.1
Crypsis *Crypsis aculeata*	--	--	--	--	Trace	4.8	--	--	Trace	2.2	Trace	1.0	Trace	1.5
Fescue *Festuca* sp.	--	--	--	--	Trace	2.4	--	--	--	--	Trace	1.0	Trace	0.7
Panic grass *Panicum* sp.	Trace	3.8	--	--	--	--	--	--	--	--	--	--	Trace	0.4
Beard grass *Polypogon monspeliensis*	--	--	--	--	--	--	Trace	3.0	Trace	2.2	--	--	Trace	0.7
Foxtail *Setaria* sp.	--	--	Trace	3.1	--	--	--	--	--	--	--	--	Trace	0.4
Milo *Sorghum vulgare*	--	--	--	--	--	--	--	--	--	--	Trace	1.0	Trace	0.4
Spikerush *Eleocharis palustris*	--	--	Trace	3.1	Trace	4.8	Trace	6.0	--	--	--	--	Trace	1.8
Sedge *Carex* sp.	--	--	Trace	3.1	--	--	--	--	--	--	--	--	Trace	0.4
Toadrush *Juncus buffonis*	--	--	--	--	Trace	4.8	--	--	--	--	--	--	Trace	0.7
Knotweed *Polygonum lapathifolium*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Lady's thumb *Polygonum persicaria*	Trace	3.8	--	--	--	--	--	--	--	--	--	--	Trace	0.4
Sheep sorrel *Rumex acetosella*	--	--	--	--	--	--	Trace	9.0	--	--	--	--	Trace	1.1
Mexican tea *Chenopodium ambrosioides*	--	--	Trace	3.1	--	--	--	--	--	--	--	--	Trace	0.4

Miner's lettuce *Montia perfoliata*	Trace	7.6	--	--	--	--	--	--	--	--	--	--	Trace	0.7
Mouse-ear chickweed *Cerastium viscosum*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Carter's buttercup *Ranunculus alveolatus*	Trace	3.8	Trace	19.2	Trace	7.3	Trace	6.0	--	--	--	--	Trace	4.0
Cursed crowsfoot *Ranunculus sceleratus*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Wild radish *Raphanus sativus*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Shining pepper-grass *Lepedium nitidum*	--	--	--	--	--	--	Trace	3.0	--	--	--	--	Trace	0.4
Lupine *Lupinus bicolor*	--	--	--	--	--	--	--	--	--	--	Trace	1.0	Trace	0.4
Clover *Trifolium* spp.	Trace	7.6	--	--	Trace	2.4	Trace	6.0	Trace	2.2	Trace	1.0	Trace	2.5
Medick *Medicago* sp.	--	--	--	--	--	--	Trace	3.0	--	--	--	--	Trace	0.4
Yellow sweetclover *Melilotus indica*	--	--	--	--	--	--	Trace	3.0	--	--	--	--	Trace	0.4
Red-stem filaree *Erodium cicutarium*	--	--	Trace	9.3	Trace	4.8	--	--	--	--	Trace	2.0	Trace	2.9
White-stem filaree *Erodium moschatum*	--	--	--	--	--	--	--	--	Trace	2.2	--	--	Trace	0.4
Mallow *Malva* sp.	--	--	Trace	3.1	--	--	--	--	--	--	--	--	Trace	0.4
Coyote thistle *Eryngium vaseyi*	--	--	--	--	--	--	Trace	3.0	--	--	--	--	Trace	0.4
Scarlet pimpernel *Anagallis arvensis*	Trace	7.6	--	--	Trace	7.3	Trace	18.1	Trace	13.6	Trace	1.0	Trace	6.6
Bindweed *Convolvulus arvensis*	Trace	3.8	--	--	--	--	--	--	--	--	--	--	Trace	0.4
Greene's allocarya *Allocarya greenei*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Douglas' pogogyne *Pogogyne douglasii*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Yellow star thistle *Centaurea solstitialis*	--	--	--	--	--	--	--	--	--	--	Trace	2.0	Trace	0.7
Smooth cat's-ear *Hypochoeris glabra*	--	--	--	--	Trace	4.8	Trace	3.0	--	--	Trace	6.0	Trace	3.3
Tarweed *Hemizonia virgata*	--	--	--	--	Trace	2.4	Trace	6.0	Trace	2.2	--	--	Trace	1.5
Soliva *Soliva sessilis*	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4
Forb leafage	--	--	Trace	6.2	Trace	7.3	Trace	9.0	--	--	Trace	1.0	Trace	3.3
Vegetative fragments	Trace	3.8	Trace	9.3	Trace	4.8	Trace	3.0	--	--	Trace	3.0	Trace	3.6
Animal Foods:														
Seed shrimp Ostracoda	Trace	3.8	Trace	31.2	Trace	9.7	Trace	18.1	--	--	--	--	Trace	7.6
Insect fragments Insecta	Trace	3.8	Trace	19.2	Trace	9.7	Trace	9.0	Trace	4.5	Trace	1.0	Trace	5.8
Fish scales	--	--	--	--	Trace	2.4	--	--	--	--	--	--	Trace	0.4

* This supplemental list gives the frequency of occurrence in percent of those food items comprising less than 0.1 percent of the total volume of food eaten.

food eaten in August, and during the hunting season in September turkey mullein constituted 76.1 percent of the food and occurred in 95.9 percent of the 99 dove crops examined.

Turkey mullein plants begin their rapid period of growth after the spring annuals have begun to dry. They begin to fruit in the early summer and drop their seeds from late June until the fall rains occur. Seeds from the early maturing plants contribute a little over 10 percent to the diet in June and July. Turkey mullein also made up a surprising 17.0 percent of the March-April food. However, it was evident from their weather-beaten and insect-chewed condition that they were the seeds of the previous year.

Turkey mullein, sometimes called "dove weed" by the hunters, is one of the more common summer annuals that grow on the disturbed land in California. On the study area it was found most often in the sparsely vegetated fallow fields, abandoned homestead areas, roadsides and the firebreaks surrounding the grain fields. Where the spring annuals had been removed at the opportune time by early plowing or discing, turkey mullein plants flourished and exhibited a more robust and vigorous growth, not observed where they were subjected to heavy plant competition.

The only other late summer annual significant to the doves' diet was valley spurge. Its seeds made up 2.2 percent of the food total and it appeared in the diet only in August and September. Its habit of growth and location throughout the study area closely resembled that of turkey mullein.

Animal Food Items

The only significant contribution of animal food items to the diet of the dove occurred during the height of the nesting season. Insect fragments occurred in a few crops each month of the study, but apparently were picked up incidentally. However, snail fragments made up a small volume of the food eaten each month from March through August and bits of bone fragments furnished 2.0 percent of the food eaten in May. McClure has demonstrated the need of an appreciable amount of cuttlebone in the diet of captive doves and their young, and suggests the presence of snail fragments in the diet of doves in the wild probably satisfies some physiological need, possibly for calcium.

Dove Milk

In recording the food items flushed from the crops of the nestling birds on the Mather Field area, one important food item was not placed in Table 1. That item is "dove milk" and, of course, is an essential food only to the nestling birds. This substance consists of small yellowish curds of epithelial tissue which proliferate and slough off of the thickened wall of the parent bird's crop, and is regurgitated and fed to the young. This dove milk constitutes the bulk of the diet of the 1- to 3-day-old birds and the amount fed the young apparently decreases as they develop.

Four 1- to 3-day-old nestlings were examined. Their crops contained 75-90 percent dove milk, and 10-25 percent of the seeds of red maids, Carter's buttercup and California poppy. McClure also found an ap-

preciable amount of seeds in the crops of very young nestlings. Evidently they are fed a few seeds along with the dove milk from the time they are able to lift their heads and take food.

Sixty of the crops obtained from the 4- to 12-day-old birds contained an average of 25 percent dove milk; the remainder being seeds and some snail fragments. There also is evidence that the parent doves attend the young for at least a short period after they fledge. Dove milk was found in "trace" amounts in the crops of eight of the immature birds collected by shooting.

CONCLUSION AND SUMMARY

The Mather Field mourning dove study area which is east of Sacramento, California, was selected for an intensive ecological food habits investigation. It is a 40-acre abandoned orchard isolated by fallow fields. The study area was divided into its physiographical units: orchard, cultivated field, fallow field, rangeland, vernal pool, and roadside; and vegetative composition plots were maintained. A check list of 107 plant species was compiled.

The doves first arrive on the study area in appreciable numbers during the month of April. The peak of the nesting season occurs near the middle of June and the actual number of nests varies from year to year. By the end of the hunting season in September few doves remain in the study area.

A total of 275 mourning dove crops was examined, including the contents of 70 nestling crops. The food consisted of 99.6 percent seeds and 0.4 percent animal food items. The seeds of 71 plant species were identified, 55 of which were found growing on the area. However, the seeds of just *eleven* of these plants made up over 97 percent of the food found in the crops. These are turkey mullein, red maids, wheat, milk thistle, windmill pink, valley spurge, buckthorn weed, California poppy, frying-pans, and Napa thistle. Of these, red maids and turkey mullein proved to be the two most important food sources on the area; red maids during the spring and early summer months and turkey mullein during the late summer. Wheat also is considered a preferred food, especially after the harvest season.

The seasonal consumption of the 11 preferred plants shows clearly that the seeds of these plants are utilized as they become available. The majority of these plants are found most abundantly in the fallow and cultivated fields and it was these locations that proved to be the most attractive feeding grounds on the Mather Field dove study area.

The use of animal food items was insignificant except for small percentages of snail and bone fragments, possibly a source of calcium for the nesting birds.

Dove milk was an important food item of the nestling birds, making up 75-90 percent of the food identified in the crops of 1- to 3-day-old birds and an average of 25 percent of the food in the 4- to 12-day-old dove crops. "Trace" amounts also were found in some of the crops examined from immature doves already fledged. The young mourning doves depend wholly upon the dove milk and seeds for their early food requirements rather than on a diet of insects which many other birds require, e.g., the Galliformes.

It should be noted that many of the dominant annuals found on the study area, such as broad leaf filaree and the common annual grasses, as well as cultivated oats, were found to contribute virtually nothing to the diet of the Mather Field doves. From its choice of food items on the Mather Field dove study area, whether by availability or preference, it is apparent that the mourning dove is highly selective in its diet.

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APPENDIX

TABLE A-1

Check List of Plants Identified from Mather Field Study Area

Plant	Orchard	Cult. field	Fallow field	Waste field	Vernal pool	Roadside
Arrow-grass Family *Juncaginaceae*						
Flowering quillwort *Lilaea subulata*	-	-	-		XX	-
Water-plantain Family *Alismaceae*						
Fringed water-plantain *Damasonium californicum*	-	-			X	
Grass Family *Gramineae*						
Goatgrass *Aegilops triuncialis*	-	-	-	X		X
Bentgrass *Agrostis avenacea*	-	-	-	-	X	-
Silver hairgrass *Aira caryophyllea*	XX	-	-		XX	-
Meadow foxtail *Alopecurus praetensis*	-	-			XX	
Slender oat *Avena barbata*	XX	-	-	-	-	
Wild oat *Avena fatua*	XX	-	-	-	-	XX
Cultivated oats *Avena sativa*	-	XXX	XX		-	
Quaking grass *Briza minor*	-	-	-	X	-	X
Soft chess *Bromus mollis*	XXX	X	XX	XXX	-	XXX
Rip-gut *Bromus rigidus*	XX	-	XX	XX	-	XXX
Red brome *Bromus rubens*	XX	-	XX	XX	-	XX
Bermuda grass *Cynodon dactylon*	-	-	-	-	-	X
Annual hairgrass *Deschampsia danthonioides*					XXX	-
Fescue *Festuca dertonensis*	XX	-	X	XX		
Meadow barley *Hordeum brachyanthcrum*	X			-	X	
Darnel *Lolium temulentum*	-	X		X	X	XXX
Canary grass *Phalaris minor*	-	-	-		X	-
Blue grass *Poa annua*	-	-	-	-	X	-
Beard grass *Polypogon monspeliensis*	-	-	-		X	
Wheat *Triticum aestivum*	-	XXX		-		-
Sedge Family *Cyperaceae*						
Spikerush *Eleocharis palustris*	-	-			XXX	
Rush Family *Juncaceae*						
Wire rush *Juncus balticus*	-	-	-		X	
Toad rush *Juncus buffonis*	-	XX	XX	-	X	X
Lily Family *Liliaceae*						
Blue dicks *Brodiaea capitata*	X			X		X
Harvest brodiaea *Brodiaea coronaria*	-	-	-	-	XX	X
White brodiaea *Brodiaea hyacinthinia*	-	X	X		-	X
Grass nut *Brodiaea laxa*	X	-	-	X	-	X
Yellow mariposa *Calochortus luteus*	-	-		-	-	X
Buckwheat Family *Polygonaceae*						
Sheep sorrel *Rumex acetosella*	X	-	X	XX	-	
Green dock *Rumex conglomeratus*	-	-	X		-	X
Curly dock *Rumex crispus*	-	-	-	-	-	X
Fiddle dock *Rumex pulcher*	-	-	X	-	-	-
Saltbush Family *Chenopodiaceae*						
Lamb's-quarters *Chenopodium album*	-	-	X	-	-	
Amaranth Family *Amaranthaceae*						
Rough pigweed *Amaranthus retroflexus*	-	-	X	-	-	X
Purselane Family *Portulacaceae*						
Red maids *Calandrinia caulescens*		XXX	XXX	-	X	X
Pink Family *Caryophyllaceae*						
Mouse-ear chickweed *Cerastium viscosum*	X	-	XX	-	-	X
Western pearlwort *Sagina occidentalis*	-	-	X	-	-	-
Windmill pink *Silene gallica*	-	XX	XX		-	X
Corn spurrey *Spergula arvensis*	X	-	X		-	-
Sand spurrey *Spergularia bocconei*	-	-	-	-	-	X
Common chickweed *Stellaria media*	X	-	-	-	-	-
Buttercup Family *Ranunculaceae*						
Carter's buttercup *Ranunculus alveolatus*	-	-	-	-	XX	-
California buttercup *Ranunculus californicus*	-	-	-	X		X
Poppy Family *Papaveraceae*						
California poppy *Eschscholtzia californica*	-	-	-	X	-	X
Frying-pans *Eschscholtzia lobbii*	-	-	-	X	-	X
Cream cups *Platystemon californicus*	-	-	-		-	X

TABLE A-1—Continued

Check List of Plants Identified from Mather Field Study Area

Plant	Orchard	Cult. field	Fallow field	Waste field	Vernal pool	Roadside
Mustard Family *Cruciferae*						
Common yellow mustard *Brassica campestris*	--	X	X	--	--	X
Shepherd's purse *Capsella bursa-pastoris*	--	--	X	--	--	X
Common pepper-grass *Lepidium nitidum*	--	--	X	--	--	X
Wayside pepper-grass *Lepidium bipinnatifidum*	--	--	--	--	--	X
Wild radish *Raphanus sativus*	X	X	XX	--	--	--
Fringe-pod *Thysanocarpus curvipes*	--	--	--	--	--	X
Pea Family *Leguminosae*						
Hill lotus *Lotus humistratus*	XX	--	--	X	--	XX
Small-flowered lotus *Lotus micranthus*	X	--	--	--	--	--
Lindley's annual lupine *Lupinus bicolor*	X	X	X	X	--	X
Bur clover *Medicago hispida*	X	--	--	X	--	--
Dwarf sack clover *Trifolium depauperatum*	--	--	--	--	--	X
Small-headed clover *Trifolium microcephalum*	X	--	--	--	--	--
Tomcat clover *Trifolium tridentatum*	--	--	--	--	XX	--
Vetch *Vicia americana*	--	X	X	--	--	XX
Geranium Family *Geraniaceae*						
Red-stem filaree *Erodium cicutarium*	--	--	X	--	--	--
Broad-leaf filaree *Erodium botrys*	XXX	XX	XXX	XXX	X	XXX
Meadow Foam Family *Limnanthaceae*						
Valley foam *Limnanthes rosea*	--	--	--	--	--	XX
Spurge Family *Euphorbiaceae*						
Turkey mullein *Eremocarpus setigerous*	XX	XX	XX	XX	--	X
Valley spurge *Euphorbia ocellata*	--	--	X	X	--	X
Mallow Family *Malvaceae*						
Annual sidalcea *Sidalcea calycosa*	--	--	--	--	X	--
St. John's Wort Family *Hypericaceae*						
Tinkers penny *Hypericum anagalloides*	--	--	--	--	--	X
Loose-strife Family *Lythraceae*						
Grass poly *Lythrum hyssopifolia*	--	--	--	--	XXX	--
Parsley Family *Umbelliferae*						
Coyote-thistle *Eryngium vaseyi*	--	--	--	--	XXX	X
Shepherd's needle *Scandix pecten-veneris*	--	--	--	--	--	X
Primrose Family *Primulaceae*						
Scarlet pimpernel *Anagallis arvensis*	X	X	X	--	--	--
Gentian Family *Gentianaceae*						
Canchalagua *Centaurium venustum*	X	--	--	--	--	--
Morning-glory Family *Convolvulaceae*						
Bindweed *Convolvulus arvensis*	X	--	--	X	--	X
Gilia Family *Polemoneaceae*						
White-flowered navarretia *Navarretia leucocephala*	--	--	--	--	XXX	X
Borage Family *Boraginaceae*						
Greene's allocarya *Allocarya greenei*	--	--	--	--	--	X
Stipitate allocarya *Allocarya stipitata*	--	--	--	--	XXX	--
Rough-fruited allocarya *Allocarya trachycarpa*	--	--	--	--	--	X
Buckthorn weed *Amsinckia douglasiana*	--	--	X	--	--	X
Mint Family *Labiatae*						
Douglas' pogogyne *Pogogyne douglasii*	--	--	--	--	XXX	--
Vinegar weed *Trichostema lanceolatum*	X	--	X	X	--	--
Nightshade Family *Solanaceae*						
Tolguacha *Datura meteloides*	--	--	X	--	--	--
Figwort Family *Scrophulariaceae*						
Valley tassels *Orthocarpus attenuatus*	X	--	--	--	X	XX
Field orthocarpus *Orthocarpus campestris*	--	--	--	--	XXX	XX
Johnny-tuck *Orthocarpus erianthus*	--	--	--	--	XX	XX
Escobita *Orthocarpus purpurascens*	--	--	--	--	--	X
Dwarf orthocarpus *Orthocarpus pusillus*	--	--	--	--	--	X
Madder Family *Rubiaceae*						
Bed straw *Galium aparine*	X	--	--	--	--	--
Lobelia Family *Lobeliaceae*						
Dowingia *Dowingia elegans*	--	--	--	--	XXX	X

TABLE A-1—Continued

Check List of Plants Identified from Mather Field Study Area

Plant	Orchard	Cult. field	Fallow field	Waste field	Vernal pool	Roadside
Sunflower Family *Compositae*						
Mayweed *Anthemis cotula*	--	X	X	X	--	X
Blow-wives *Achyrachaena mollis*	--	--	X	--	--	X
Gold fields *Baeria fremontii*	--	--	--	--	XXX	X
Napa thistle *Centaurea melitensis*	--	--	X	--	--	--
Yellow star thistle *Centaurea solstitialis*	--	X	X	--	--	X
Brass buttons *Cotula coronopifolia*	--	--	--	--	X	--
Cotton-batting plant *Gnaphalium chilense*	--	XX	XX	--	--	--
Gum plant *Grindelia camporum*	--	--	X	--	--	X
Common sunflower *Helianthus annuus*	--	--	X	--	--	X
Virgate tarweed *Hemizonia virgata*	XX	--	X	XX	--	XX
Smooth cat's-ear *Hypochoeris glabra*	XX	XX	XX	XX	--	XX
Tidy tips *Layia platyglossa*	--	--	--	--	XX	XX
Common madia *Madia elegans*	--	--	--	--	--	X
Pineapple weed *Matricaria suaveolens*	--	--	--	--	--	X
Milk thistle *Silybum marianum*	--	--	X	--	--	--
Wyethia *Wyethia helenioides*	--	--	--	--	--	X
Cockle bur *Xanthium canadense*	--	--	X	--	--	--

NOTE:
X—Occasional
XX—Common
XXX—Abundant

Sources for the scientific and common names found on this list are: Jepson (1923), Abrams (1940-1951), and Robbins, Bellue & Ball (1951).

GAME WATER DEVELOPMENT ON THE DESERT[1]

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INTRODUCTION

Water or the lack of it, is a major controlling factor on game populations in arid areas. In comparatively well watered areas there are often dry localities where water development will enable game concentrations to spread out, and thus increase the carrying capacity of the range.

Spring development is not a complicated procedure. It consists mostly of hard manual labor in making water available to game, or of concentrating and conserving a small water supply. Most springs may be grouped as either good and not needing development, or as wet-weather springs that dry up and can't be improved because they are not permanent. The good springs, unless remote, are usually appropriated by local residents. So it is the marginal spring that is generally improved and developed for game.

Seasonal or wet-weather springs are important to game during the period when water is available, but do not usually warrant expenditure of effort or money for development. Unfortunately, some springs will sooner or later go completely dry. Therefore, it is extremely important to check as many potential locations as possible during the fall of the year before the winter rains begin, and during the driest years. These periods are best for locating an exact water source and for determining what development work would be necessary.

Water that flows over bedrock usually can be considered seasonal and will dry up with prolonged drought. Permanent water if dug to its source, is almost always found to be coming from rock formations. Some springs may fluctuate very little, either with the seasons or from year to year. An excellent example of this type is Mopah Spring in the Turtle Mountains in southeastern San Bernardino County. The flow is small but constant. It is located near the head of a canyon in an extremely arid mountain range with an annual average rainfall of less than four inches. These springs cannot be explained in the usual manner and are certainly not the result of local drainage. Mendenhall (1909), stated "The greater permanent springs are deep-seated, and many of them probably lie along fault lines."

WATER INDICATOR PLANTS

Water-indicating plants provide a tool in looking for water sources. They vary in different locations with the climate and elevation (Meinzer, 1927). It is the author's belief that they can survive some

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drought and exist for a period of time on only seasonal rainfall. Therefore, the plant is not necessarily an indicator of permanent water, so the condition of the plant becomes the important factor. If considerable deadwood is present it can be assumed that the water is seasonal. Conversely, if the plants are in good condition during the dry season, it is probable that their roots are in a permanent water supply of undetermined depth.

Mesquite, *Prosposis* sp. is a common tree of the desert and usually grows in areas of shallow water table. Many desert residents believe that a well can be dug in less than 40 feet at mesquite growths. On the contrary our conclusion is that mesquite will survive after long droughts and that mesquite, by itself, is not a positive indicator of water at any depth. Mesquite and its relation to depth to water is discussed at some length (Brown, 1923).

Arrow-weed, *Pluchea sericea* which grows at low elevation in the warm southern deserts, is a good water indicator. Although it is not known to what depth it roots, it is thought to be an indicator of permanent water if the plants are thrifty and without deadwood in a dry period. Other indicator plants are wildrose, *Rosa* sp., and common reed, *Phragmites communis*. Salt grass *Distichlis spicata* and other grasses generally indicate favorable moisture conditions.

Some plants that favor moist conditions but are not positive water indicators are tanglebrush *Forestiera neomexicana*, desert baccharis *Baccharis sergiloides*, saltbush *Atriplex* sp., cottonwood *Populus* sp. and salt cedar *Tamarisk*.

COMPETITION

Before developing a spring for wildlife it is important to consider the other use it will receive, such as, by domestic livestock or undesirable feral animals. The development of water may have an adverse effect on game if it results in greatly increased range use by competing animals. This is not intended to be a condemnation of domestic livestock grazing, but only to point out that this phase of the problem should be carefully considered and appraised.

Light or infrequent use of game water developments by livestock may be of little consequence, but where the supply is small a few animals attracted to the development can completely usurp the available water. This is frequently the case with feral burros if they are present in or adjacent to the area.

Our water development crew has never attempted to construct exclosures but they are worthy of consideration where the terrain permits application (Halloran and Deming, 1956).

Ranchers should clearly understand the purpose before any waters are developed by a public agency on their livestock range. A legal agreement between the landowner and the agency doing the development should be required.

TOOLS

The main tools of water development are the pick, mattock, and shovel. A portable hammer is necessary on many projects, and there are several kinds available. Rock drills of two- and three-foot lengths are necessary, as are chisels, spades, gads, and malls. If the location is accessible it is

FIGURE 1. Butcherknife Spring. Spraying new willow growth with 2,4-D and 2,4-5T, using a back tank. This work restored a 50-gallon pool that had dried.

more efficient to use pneumatic tools with a compressor. Handwork is time consuming and costly.

Although the use of dynamite on springs is considered by some to be inadvisable, it is an efficient, useful tool. The source of permanent water is frequently found in rock strata and it is practically impossible to dig in hard rock without explosives. Dynamite has been used many times without loss of a spring. When springs are lost through the use of an explosive, it is usually the result of a heavy charge opening a crack which allows the water to escape.

Dynamite should be used only on marginal seeps where there is insufficient water immediately available. It is useful also in clearing a storm channel to bypass and thus protect a spring or to lay a pipe for gravity flow.

The burning of plant life on a water development site often is employed where such burning can be safely controlled. It is much easier to determine the ground formation and probable source of water when the location has been cleared by fire. At Toro Spring in the Santa Rosa Mountains, burning a dense arrow-weed thicket was all that was necessary to produce a flow amounting to 10 gallons per hour. Periodic reburning may be necessary.

Spraying with the brush killer 2,4-D or 2,4-5T is useful (Biswell and Schultz, 1958). Plants such as willow waste a great amount of water through transpiration, and may cause a spring to be completely dry during the summer. When the plants are killed the spring will often return to normal flow. This has proved to be useful practice in instances of a small water supply. The loss of cover or shade is more than offset by making a permanent water supply available to game.

The use of an airplane has been employed successfully in locating remote springs, seeps, and tanks. Green growth or converging game trails will reveal locations that can later be investigated on foot.

Back packs or pack horses are used to take materials into remote locations that can't be reached with four-wheel-drive vehicles.

Materials most commonly used on spring development include redwood lumber, galvanized or plastic pipe, Orangeburg asphalt pipe, rock masonry and cement.

TYPES OF DEVELOPMENT

Ramps

Young game birds and animals often drown in abandoned wells and flooded mine shafts, but these death traps can be converted into safe watering places for wildlife by construction of a ramp.

The ramp should extend two or three feet below the water level, giving an ample pool at which the game can drink. Although our crew has constructed a ramp 13 feet below ground level, in most cases 10 feet will be a maximum depth that can be worked with ordinary tools. A slip scraper pulled by a truck is useful in removing material to form the ramp.

Unless the ramp is cut through rock it probably will be necessary to rock or board up the sides to keep material from falling into and filling the pool. If the shaft is deeper than the ramp, the top of the shaft should be covered. The width of the ramp should be a minimum of three feet so as to allow livestock room to turn. If the ramp is too narrow, stock may become trapped and die.

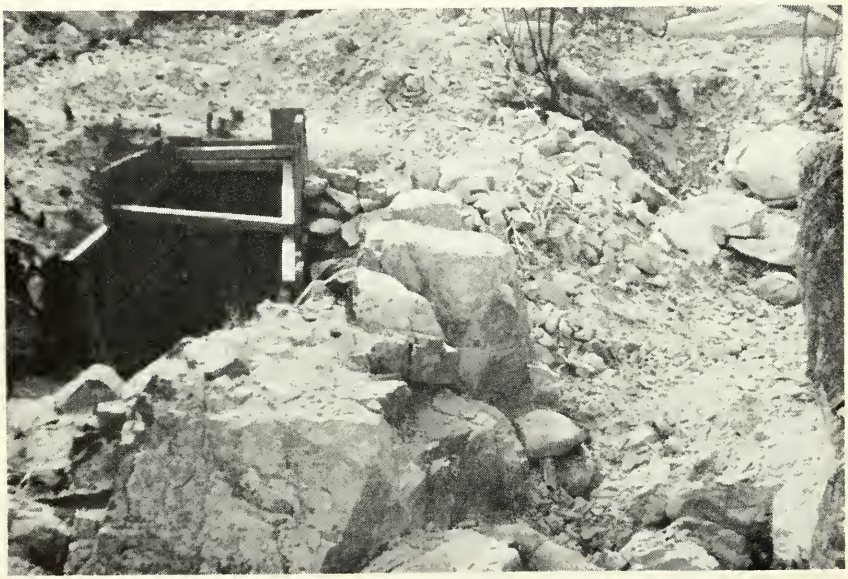

FIGURE 2. Butcherknife Spring. A ramp or walk-in well constructed and cribbed with redwood. Channel at right was blasted out with powder to bypass storm water.

Ramp-type construction also is employed where water is found other than in shafts. Ramps or walk-in wells offer a simple inexpensive method of making water available to game. They are used where it is

FIGURE 3. Paramount Spring. A ramp was constructed at a Coyote nose hole that contained water. The ramp was cribbed with redwood and a masonry wall constructed to keep storm water out.

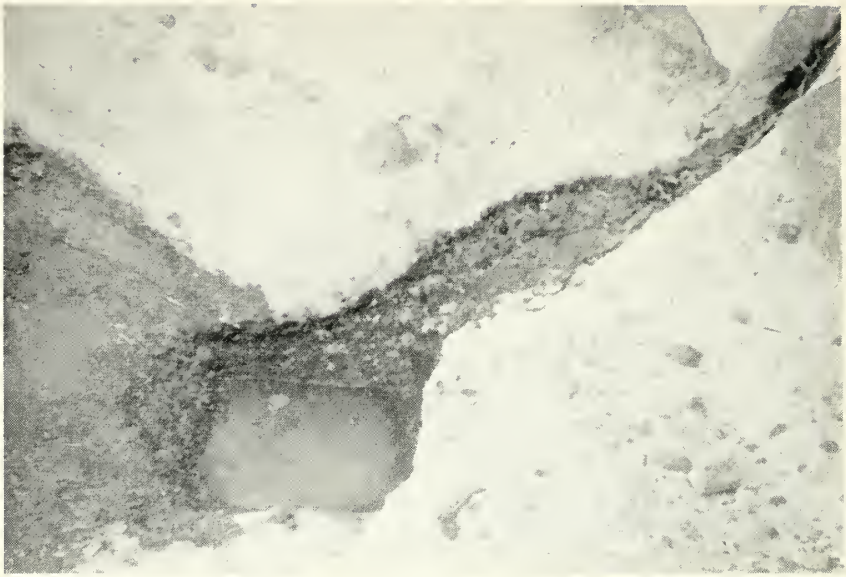

FIGURE 4. Pickie Poke Spring. Basin created with a hammer and gad point in hard, volcanic conglomerate rock. Small seep (two gallons per hour) normally wasted is stored and receives heavy game use.

impractical to pipe the water either because the depth and length of the necessary trench would be prohibitive or, because the water recharge rate of the shaft is so small it could not withstand constant drainage. It may be necessary to construct masonry walls to keep storms from flooding this type of construction.

Mechanical devices such as float valves are to be avoided in spring development work because they usually require frequent attention. For the same reason siphons are not generally used.

Basins

Basins or pools may be constructed at the source of water to conserve the supply and make it available to game. They may be constructed with rock, of cement, or masonry.

When small seeps are found to be coming from rock strata, pools may be constructed in the rock to catch and store water. One method used when the location is remote and transporting tools is a problem, is to gouge out a basin in the rock. This is slow and tedious work (Figure 4). If it is possible to get drill equipment to such a location, a considerably larger pool may be blasted out of the rock (Figure 5). Care must be taken not to shoot too hard and lose the water source or crack the basin so it will not hold water.

Rock basins are practically indestructible. If a flood does fill such a basin with sand and rock, coyotes and other animals will probably dig down in the sand and make the water available again.

Cement may be used to construct pools to catch and store water from seeps or springs, or to enlarge either natural or created rock pools.

FIGURE 5. Magnesia Spring. A compressor and jackhammer were used to create this basin in solid rock. Priar to development this small seep was unavailable to game and dried diurnally.

Excavated Springs

Most springs are found in canyon bottoms, and it is often difficult to protect development work from storm damage. A method found satisfactory is to bury a short length of perforated "Orangeburg" asphalt soil pipe in packed gravel at the water source, and to pipe the water from that collection point into a basin or trough placed out of the canyon bottom (Figure 6). This allows storm water to flow over the buried source of the spring water without damage to the development work.

Plastic pipe is usually preferred to galvanized iron pipe because it is light and easy to transport and lay. Caution must be taken to insure that the pipe will not wash out during floods, freeze, or be damaged by livestock. The pipe should be laid to grade to avoid air locks.

A perforated tipped plastic pipe inserted into a redwood spring box has been used successfully. The spring should be rocked or cased and a cement cover with a manhole should be installed. This permits entry to cut roots and do other maintenance. It also allows storm water to flow over the development without damage.

A cement, or cement and rock basin or trough is the preferred construction, although a metal trough, cylinder or barrel may be used if no aggregate is at hand. The metal should be galvanized or otherwise treated to prolong its life. If a deep trough is used, a ramp for birds is desirable to minimize the hazard of drowning.

FIGURE 6. Surveyor's Spring. Excavated, and perforated Orangeburg asphalt pipe installed and gravel-packed. Plastic pipe installed to carry water to a basin out of the canyon bottom. This type of development has been used on springs producing a flow of as little as one gallon per hour to as much as 75 gallons per hour.

OTHER SPRINGS OR WATER SOURCES

On rare occasions a location is found where simple excavation will produce a strong flow of water, and where no piping or storage basin is required.

There are locations where an adequate supply of water exists but does not reach the surface because it is used and transpired by the dense growth of hydrophytes. Such water can be made available to game by opening the source or sources usually found near the upper edge of the heavy growth. Ursina Spring in the Providence Mountains of San Bernardino County is an example where a flow of 15 gallons per hour was produced by control of vegetation and exposing the source. The prior condition was that of a seep.

Although seasonal springs do not warrant extensive work, the water they produce during the winter and spring might profitably be collected and stored for use by game during the dry season.

There is little that can be done to improve natural tanks or *tenajas*. They are important to wildlife and in some desert mountain ranges are the only source of water. It has been noted that deep and well-shaded tanks retain water the longest. One large exposed tank (Figure

FIGURE 7. Black Tank. Experimental suspension roof built to shade natural tank or *tenaja*. Constructed from salvage material. Cable stretched with a turnbuckle. Tank is eight feet deep and holds an estimated 30,000 gallons.

7) was covered with a suspension roof built from salvaged cable, pipe, and sheet metal. This work has not been completed long enough to permit evaluation of its effectiveness.

Although the California Department of Fish and Game has installed over 2,000 "gallinaceous guzzlers" for birds and small game, only a few big game guzzlers have been built and they have not been fully evaluated.

The guzzlers are mechanically sound and they certainly work well for small game. Rain water is collected by a large apron and stored in a large covered or underground tank or series of tanks. A ramp leading down into the tank makes the water available to game.

MAINTENANCE

Game water developments should be constructed so that a minimum amount of maintenance is necessary. Periodic rechecking is required since debris may accumulate in the basins or pipes. Development work may be buried or destroyed by cloudbursts; therefore, to prevent this it is often necessary to construct a stone diversion wall (Figure 2) or to blast boulders creating a new storm channel. Water-dissipating plants may need respraying to effect control.

Periodic checking also permits evaluation of the development and its effectiveness. The experience gained on each site helps point the way to more effective and trouble-free watering sites for game in the future.

Mapping is essential so that persons other than those who did the development work can find the locations. If a location requiring periodic maintenance is lost and becomes unserviceable—all of the time, effort, and money spent on its development has been wasted.

SUMMARY

The experience of game management personnel in the desert has shown the following points to be important in water development:

1. Marginal seeps and springs can be improved by making the water available or by conserving it.
2. The condition of water indicating plants of a given area can be a key to possible development sites.
3. Water development may have an adverse effect on game if there is subsequent over-utilization by competing animals.
4. Hand tools are the most important items used in spring development. Dynamite can be used successfully. Burning and chemicals may control water usurping plants.
5. Walk-in ramps, storage basins and excavated springs are common methods of improving sites.
6. Constructions should require a minimum of maintenance, but periodic surveys are necessary to determine if structures need cleaning or repair.

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IMMUNIZATION OF PHEASANTS WITH BOTULINUM TOXOID[1]

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INTRODUCTION

There have been sporadic but severe outbreaks of avian botulism for many years on some of the California State Game Farms. The game farm at Fresno has experienced the most severe mortality rates. Of about 10,000 to 12,000 birds produced annually, the losses have exceeded 40 percent during bad years.

Conditions exist on a game farm that are intrinsic to its physical facility and operation, but which unnecessarily foster the occurrence of botulism. Most game farm managers have a deep-seated belief that it is necessary to raise a large stand of herbaceous cover within the pens, and that the more luxuriant the growth the better his pheasants will fare. This cover crop does serve as a preventive of tail picking among the crowded pheasants within a pen. However, it performs a twofold disservice in that the soil is kept moist, and sick or dead birds are hidden form the caretakers. The accumulation or droppings together with warm moist conditions may be one prerequisite to the initiation of botulism. A dead bird with maggots is the introduction to an outbreak with serious losses, inasmuch as the maggots serve to concentrate the toxin and are fed upon readily by the pheasants. One further situation that tends to encourage the appearance of botulism is the use of concrete watering troughs that are allowed to overflow daily.

Various measures have been applied in attempts to control the intoxication. Almost every conceivable type of watering device, commercial or locally designed, has been tried. Cover crops were reduced to thin strips, and at other times they were replaced by artificial wooden covers. Spraying with insecticides was employed as a means of ridding the farm of the large numbers of toxin laden larvae.

The most promising measures consisted of removal of the cover crop combined with diligent search for and removal of carcasses. However, the end product was the pheasant typically tail picked. This defeathered bird, apart from considerations of cannibalism, costs more due to the additional seasonal employees needed to march through the pens twice daily gathering dead birds. It was evident that this could limit the losses, but another method might be employed that could be more economical and produce a better pheasant for liberation.

Cheatum *et al* (1957) suggested the use of toxoid for prophylaxis against *Clostridium botulinum* Type C intoxication in pheasants. The

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procedure has been reported as a success in immunizing mink (Larsen *et al*, 1955), (Appell *et al*, 1956). Based on those ideas and results, several pilot studies and a large scale field trial involving more than 10,000 pheasants was undertaken. The techniques used and the results obtained are reported herein.

ACKNOWLEDGMENTS

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PILOT STUDIES

Toxin Titrations

In the initial study of the protection afforded by toxoid, it was first necessary to determine the strength of the toxin that would be used to challenge the pheasant's immunity. In the titration, two routes of administration were used, wherein one ml. of toxin was inoculated intraperitoneally in the first group of birds, and one ml. was administered orally to a second group. This procedure was used for the toxin supplied by American Scientific Laboratories, Inc., (ASL), but American Cyanamid Company (ACC) toxin was used by the intraperitoneal route only. The results shown in Table 1 indicate that the intraperitoneal LD_{50} for ACC is $10^{-1.69}$; the oral and intraperitoneal LD_{50} for ASL are $10^{-0.76}$ and $10^{-2.69}$ respectively. The method published by Reed and Muench (1938) was used to calculate the LD_{50}. Subsequently the toxin was titrated each time before challenge tests inasmuch as there was variation in titer. These titrations were carried out by intraperitoneal injection of one ml. ASL toxin was received in a lyophilized condition and restored to original volume. The diluent used to restore the toxin was composed of 0.2 percent gelatin in a phosphate buffer at pH 6.2. ACC toxin was received as a liquid and used accordingly.

TABLE 1

Titration of Commercially Prepared Toxin in Pheasants

	ACC				ASL				
Dilutions	—	10^{-1}	10^{-2}	10^{-3}	—	10^{-1}	10^{-2}	10^{-3}	10^{-4}
Intraperitoneal	5/5	5/5	0/5	0/5	7/7	7/7	6/6	1/6	0/6
Oral					7/8	3/7	0/6	0/6	0/6

Numerator—number dead; denominator—number challenged.

Toxoid Immunization

The botulinum Type C toxoid suplied by both companies was prepared originally for mink. No information on the preparation of that sent by ACC was received other than that it was a bacterin. The ASL product was a formalinized whole culture with high toxoid content, with an aluminum adjuvant.

The first immunity study was conducted with ASL toxoid in December, 1957. Three yards at the Sacramento Game Farm were set up with 50 adult pheasants in each, and a fourth yard contained 43. The schedule of immunization was set up so that the dosage for each yard was one ml. per bird containing the equivalent of undiluted toxoid in yard one, 0.5 in yard two, 0.33 in yard three, and in yard four 37 birds got 0.25 and six birds received 0.1. All inoculations were given by the subcutaneous route.

Four weeks after toxoid inoculation, the 193 pheasants were challenged with one ml. undiluted toxin. Within four hours the typical symptoms of botulism developed in many of the subjects. The final results of the test were 30 survivors of the 50 in yard one, 17 of 50 in yard two and in yard three, and 22 of the 43 in yard four. The calculated protection was in the neighborhood of 17 LD_{50} with no significant difference between the various doses of toxoid. This was based on a titration of toxin in which the potency was found to be considerably less than that originally encountered.

The next pilot studies were done with ACC toxoid. One hundred adult pheasants were injected intramuscularly with one ml. of toxoid. Thirty days later five birds were challenged with five ml. undiluted toxin and 20 were given one ml. One of the five and 11 of the 20 survived their respective challenge doses. It may be concluded that this was a resistance of about 20 times the original LD_{50}. The remaining 75 pheasants were given one ml. of toxoid as a second dose to enhance their immunity. Sixty days after the initial injection, or 30 days after the "booster shot," the pheasants were challenged with all of the toxin on hand regardless of the source. The dosages were calculated on the basis of the titration that ASL was 10 times more potent than ACC toxin. The result of the challenge test is illustrated in Table 2.

TABLE 2

Degree of Immunity Shown by Pheasants After Two Intraperitoneal Inoculations and Challenged With Two Commercial Toxin Products

Toxin source	Dosage	LD_{50}	Results
ACC	1 ml	20	0/20
ACC	2 ml	40	0/10
ACC	5 ml	100	0/10
ASL	2 ml x 10^{-1}	40	0/6
ASL	5 ml x 10^{-1}	100	0/7
ASL	1 ml	200	1/7
ASL	2 ml	400	0/8
ASL	5 ml	1000	3/4*

* Three birds died of accidental injury.
Challenge by intraperitoneal injection.
Repeated toxin titration gave tenfold strength of ASL.
Numerator—deaths; denominator—number challenged.

Cursory examination of Table 2 indicates that the protection following two inoculations with toxoid exceeded 400 LD_{50} by the intraperitoneal route. Interpolating from the initial toxin titrations of the oral and intraperitoneal methods of administration, it is indicated that a possible protection exists against 34,000 oral lethal doses at the 50 percent end point of toxin produced by ASL.

FIELD TRIAL

Materials and Methods

As the arrangements necessary to conduct a large scale field trial involved practically all of the 13,000 pheasants produced at the Fresno Game Farm in 1958, considerable preliminary planning was essential so as to minimize the actual immunization operation as it related to the normal functions of the installation. Battery brooder equipment was shipped in from California game farms; the arrangement of the pens and the yards was altered to facilitate necessary separation and mixing of inoculated and uninoculated control birds; colony house arrangements were altered to accommodate the artificial separation of ACC and ASL inoculates; and other necessary changes were instituted. However, none of the altered procedures were such that the chances of a natural occurrence of botulism might be precluded or diminished to any extent.

During the operation of the game farm 12-day-old chicks are moved from battery brooders to colony houses, and 34-day-old chicks are moved from colony houses to outside pens. Both times of transfer were utilized for immunization to avoid additional handling. These movements were extended one week each beyond normal so as to allow time for the establishment of high level immunity titers. The pheasants were kept segregated according to whether they were treated with ACC, ASL, or untreated so as to facilitate handling for the second inoculation. Following the second inoculation, the pheasants were mixed so that birds of each of the three groups would be subjected to the same conditions within each pen or yard.

Each bird was debeaked, inoculated subcutaneously in the thigh with 0.5 ml., and wing banded for subsequent identification. All control birds were debeaked and wing banded. Every hatch was assigned a lot number and the lot divided into three groups consisting of 37.5 percent for testing ACC, 37.5 percent for ASL, and 25 percent were uninoculated as a control group.

All deaths that occurred in battery brooder or colony brooder houses were used only to adjust the figures of the remaining birds inasmuch as that mortality could not be considered attributable to botulism. On the other hand, some losses occurring in the pens or yards may have been due to causes other than botulism, but were included in the figures used for statistical analysis of the results. Because of the nature of botulism as it occurs in game farm confines, isolated or single deaths of birds were not indicative of death resulting from the ingestion of toxin, therefore these figures were not included in the final evaluation. Where many losses occurred within single pens or yards, botulism was proven by inoculation of sick pheasant serum into mice in accordance with the Quortrup and Sulheimer procedure (1943). Dipterous larvae

taken from carcasses were shown to be highly toxic by mouse inoculation and force feeding pheasants two or more such maggots. In both cases symptoms appeared in a few hours and death occurred within one or two days.

The statistical analysis of the results obtained with the three groups was treated by the analysis of the variance, testing the null hypothesis by means of the F test.

Results

Natural occurring botulism appeared in its usual severe form at the Fresno Game Farm. This test of the efficacy of toxoid immunization could not have been more opportune, however it did occur somewhat earlier than normal. The result was that some of the later lots of pheasants did not have an opportunity to develop the full titer of immunity before they were subjected to botulism. This unfortunate circumstance did reduce the numbers that could be accepted validly as being *bona fide* field trial conditions.

The first inoculation was made on June 2, 1958, and the second inoculation of that lot was completed on June 24. The last lot to be immunized received its second inoculation on August 19. Botulism appeared on July 19; at this time 37 birds died. Daily losses for the rest of July averaged 19 birds with a range of six minimum to 33 maximum mortality. During the first half of August the average losses were 33 per day ranging from 7 to 79. Sixty-one pheasants was the mean daily loss for the last half of August, with a minimum of 12 and a maximum of 150. The mortality rate dropped to less than two birds per day during the first half of September and botulism ended on September 27.

There were 11,650 pheasants allocated for the field trial. Of these, 4,450 were inoculated with ASL toxoid, 4,450 with ACC toxoid, and 2,750 were uninoculated as a control. A dog entered a colony house one night and killed 100 ACC inoculates, and an additional 25 died as a result of huddling, leaving a balance of 4,325 birds designated ACC. Sixty-three control birds died during the first stages of the experiment of various causes. The final number of birds involved in the field trial at the time botulism occurred was 11,462, of which 4,450 were ASL, 4,325 were ACC and 2,687 were control birds.

When the outbreak had ended and the field trial was considered complete, there were a total of 1,387 deaths attributable to botulism. The ACC group lost 586, ASL 353, and the control group 448. As mentioned above, these figures could not be used to calculate the efficacy of toxoid protection inasmuch as insufficient time elapsed between immunizing dose and the onset of botulism, e.g. lot 11 suffered the heaviest losses of all the lots, and this mortality occurred within one week of the second injection. However, some *immediate* heavy losses following the second injection might be attributable to loss of antibody titer as a result of the inoculation. All lots after number 8 were not used in calculating the final results (Table 3) since those did not have a minimum of two weeks after the second injection of toxoid.

As losses continued to increase in pheasants that should have been protected by the toxoid, it was decided to test their immunity. The LD_{50} of the toxin was re-established at the Sacramento Game Farm

TABLE 3

Summary of Field Trial Results

Lot*	ACC			ASL			CONTROL		
	Injected †	Deaths	Percent	Injected	Deaths	Percent	Birds	Deaths	Percent
4	875	124	14.2	875	51	5.8	760	144	19.0
5	750	13	1.7	875	12	1.4	365	12	3.3
6	875	58	6.6	875	35	4.0	532	31	5.8
8	450	36	8.0	450	46	10.2	375	159	42.4
Total	2,950	231	7.8	3,075	144	4.7	2,032	346	17.0

* Lots 1, 2, 3, and 7 were shipped to other areas.
† Two inoculations plus an elapsed time of two weeks after the second injection.

where no natural botulism could interfere with the results. A random selection of birds from all of the lots at the Fresno Game Farm that had sufficient time to establish immunity were challenged. The results confirmed the pilot study figures illustrated in Table 2, wherein the LD_{50} was about 500 times that of the unprotected pheasants.

DISCUSSION

Analysis of the results summarized in Table 3 show that the difference between the three groups is highly significant at the 1 percent level. Casual inspection of the lots indicates that there is no difference between groups in certain lots, e.g. lot 6. In other cases there is no real difference revealed on analysis between two of the three groups.

As the results of this work were being analyzed, the work of Boroff and Reilly (1959) on the immunization of pheasants against botulism was published. It was interesting to contrast their results against the preliminary results of the pilot studies and the results of the field trial. There was agreement that two injections were optimum; however, they used one ml., whereas, as a result of our early studies we dropped the dosage on the chicks to two 0.5 ml. injections. Their experiments demonstrated that a three- or four-week interval between injections produced a higher degree of immunity than two weeks. The interval used in our field trial was 22 days.

The age of first inoculation for the field trial was set for 19 days for ease of handling. Boroff and Reilly concluded that immunization could begin at one week of age. It is possible the mortality might have been lessened at Fresno if the inoculations had been started earlier. They established that the intramuscular route provided weaker protection than the intraperitoneal route, but did not test the subcutaneous injection which was used in these studies. Their finding that the active immunity lasted eight months was confirmed when Fresno pheasants were challenged 10 months after their second inoculation and were found to have retained some immunity. Table 4 illustrates the titration of ASL toxin used in the challenge, the results of which are shown in Table 5.

TABLE 4

Titration of ASL Toxin Used to Challenge Pheasants 10 Months After Immunization

Dilutions	—	1×10^{-1}	1×10^{-2}	1×10^{-3}	1×10^{-4}
	6/6	5/6	5/6	0/6	0/6

Numerator—number dead; denominator—number challenged.

TABLE 5

Challenge at 10 Months After Immunization

LD_{50}	ACC Birds	ASL Birds	LD_{50}	ACC Birds	ASL Birds
2	0/8	0/8	24	4/8	1/8
3	1/8	1/8	100	8/8	4/8
5	3/8	1/8	1000	8/8	8/8
12	5/8	1/8			

Numerator—number dead; denominator—number challenged.

From the experiment reported in Table 4, and from challenges conducted during the outbreak it is quite evident that a good immune response was obtained prior to and during the field trial. From losses suffered by the groups inoculated with toxoid it was evident that the natural occurring toxin was considerably more potent than that employed in challenge work. This was substantiated in part by inducing typical paralytic symptoms in pheasants force fed two or more dipterous larvae collected from pheasant carcasses.

There was a degree of protection given to pheasants inoculated with a commercial toxoid. It is possible that the protection can be greatly increased beyond that experienced in this work. This may be accomplished by use of another adjuvant (Boroff and Reilly, 1959); it is possible that the toxoid should be prepared from a different variety of organism (Prevot and Brygoo, 1949); or it may be done through a different route of inoculation, although Appleton and White (1959) obtained excellent results in mink by the subcutaneous route.

SUMMARY

Preliminary studies indicated that two subcutaneous injections of *Clostridium botulinum* Type C toxoid would protect pheasants against more than 400 times the LD_{50} on intraperitoneal challenge. This was interpolated at 34,000 oral lethal doses at the 50 percent level.

A field trial was planned encompassing the use of 11,650 pheasants, but it was disrupted through the appearance of natural occurring botulism. However, 6,025 pheasants had been inoculated twice and sufficient time had passed after the second inoculation for the establishment of a high degree of protection. There were 2,032 pheasants distributed among the inoculates to be considered experimental control subjects thereby providing 8,057 birds for the experiment. The combined total percentage mortalities were 4.7 for one product, 7.8 for

another, and 17.0 for the control. Challenge of pheasants at the time of the outbreak and 10 months later established the protection level and proved that the potency of natural toxin greatly exceeded that of the commercial products, and also exceeded the levels of immunity produced in the birds. However, the total losses sustained at the Fresno Game Farm from botulism were about 12 percent under conditions where the mortality rate could have been more than three times greater.

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NOTES

OCCURRENCE OF THE GIANT KIDNEY WORM, *DIOCTOPHYMA RENALE*, IN THE COYOTE OF CALIFORNIA

The giant kidney worm, *Dioctophyma renale* is the largest of the parasitic nematodes and may attain a length of one meter. The male is smaller than the female. Numerous authentic cases have been recorded from Canada and the United States. As far as is known this is the second record of this parasite from California. They have been recovered from different visceral organs, but are found most often in the right kidney of the coyote, dog, mink, wolverine, and other Canidae and Mustelidae. Infections in man have been reported in a few instances in the European literature.

Woodhead (1950) determined the complete life cycle requires two years. He found that annelid worms, which commonly live on crayfish, were the first intermediate hosts. Bullheads acquire the parasite by feeding on either annelid laden crayfish or the free living annelids. The final host acquires the adult worm from eating infected fish. Hallberg (1953) investigated the migration routes of the worm in the mammalian host and found considerable evidence to support a theory of larval migration through the duodenum into the adjacent right kidney.

During the month of April, 1959, State Trapper Jack Foster caught a female coyote, *Canis latrans*, in a swamp area just north of Lake Almanor in Plumas County. The animal was judged to be just over one year old and showed external signs of pregnancy. Upon opening the abdomen, what appeared to be an enlargement of one uterine horn was a cyst containing about one-half pint of oily amber liquid and four, large, sluggishly moving worms. The entire reproductive tract and cyst was sent to the California Fish and Game Wildlife Investigations Laboratory for identification. The nematodes were identified as adult kidney worms. These were two females 50.5 and 46 cm in length and two males one of which was 26 cm and the other 20.5 cm minus the anterior end (Figure 1). Examination of the cyst showed that it was the thickened fibrotic kidney capsule. Several ulcer like areas with calcareous or bony deposits were present on the inner surface. The reproductive organs showed no evidence of pregnancy. No other organs were available for examination and it could not be determined which kidney was involved.

Lake Almanor and its tributaries is well populated with crayfish and brown bullheads, *Ictalurus nebulosus*. Many crayfish are washed up along the shores, and fish are often stranded thereby becoming available to mammals as food. The population of coyotes is highest in these areas during winter and spring.

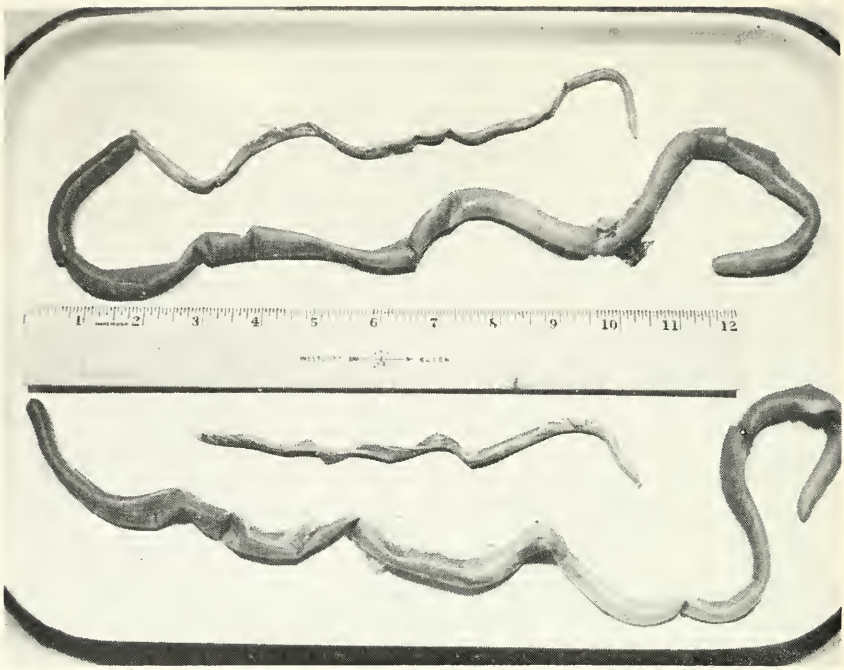

FIGURE 1. Two male and two female giant kidney worms. The large worms are the females.

A specimen of this parasite had been previously obtained from a coyote but the date and exact locality were not recorded. This was a 60 cm female found free in the abdominal cavity of a coyote trapped in northeastern California during 1954. This record was not published at the time.

It may be of interest to do some studies in this area to determine the extent of the infection in bullheads and to determine whether this parasite may be a factor in the scarcity of mink in the area.

At the time this manuscript was sent to press another occurrence was noted by Jack Foster in a male coyote taken at Round Valley Reservoir in Plumas County. This is about twenty miles south of that reported above. The worm, a 75 cm female was found free in the abdomen.

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———*Oscar A. Brunetti, Game Management Branch, California Department of Fish and Game, June, 1959.*

RECORD SILVER SALMON TAKEN IN PAPERMILL CREEK, MARIN COUNTY

On January 3, 1959, an ardent fisherman named Milton Hain of Fairfax had a dream come true. While fishing in the tidewaters of Papermill Creek near Whitehouse Pool, he hooked and landed a silver salmon (*Oncorhynchus kisutch*) which set a new record for California.

The fish weighed 22 pounds in the round and had a total length of $38\frac{1}{2}$ inches. Identification, weight and measurement were confirmed by Fisheries Supervisor, Willis Evans of the Department of Fish and Game, Region 3 and the author. The previous California record was an $18\frac{1}{4}$ pounder caught at Humboldt Bay in 1950.

Mr. Hain was using a Harnell spinning rod, a Swiss spinning reel and a six-pound test monofilament line with a "Spinnie" Daredevil lure.—*Alfred F. Giddings, Wildlife Protection Branch, California Department of Fish and Game, July, 1959.*

STRIPED BASS INTRODUCED INTO THE COLORADO RIVER

In an attempt to more fully utilize the ecological niches present in the river-reservoir system of the lower Colorado River and to add to the variety in the sport catch, an experimental introduction of striped bass (*Roccus saxatilis*) was made in the lower Colorado River on April 15, 1959. The 938 small stripers were planted immediately downstream from the U. S. Highway 60 bridge near Blythe, Riverside County. There is a possibility of developing a self-sustaining landlocked population in this section of the river.

The mean fork length of a 57 fish sample was 3.4 inches, with the range from 2.7 to 5.5 inches. However, one striped bass about 12 inches was also planted. They were seined from the San Joaquin River near the Antioch Bridge and transported in a 350-gallon planting truck. Two pounds of rock salt were added to the water and light aeration was used continuously during the transportation.

The surface water temperature in the Colorado River at the time of the plant was 65 degrees F. and the tank temperature was 60 degrees. The tank water temperature was maintained at 55 to 60 degrees throughout the 17-hour trip to Blythe. The surface temperature of the water from which they were seined was about 62 degrees.

Fifty-eight bass were lost en route; those planted appeared to be in good condition.—*J. A. St. Amant, Region 5, Inland Fisheries Branch, California Department of Fish and Game, June, 1959.*

REVIEWS

Handbook of Computations for Biological Statistics of Fish Populations

By W. E. Ricker; Fisheries Research Board of Canada Bulletin 119, Queen's Printer and Controller of Stationery, Ottawa, 1958; 300 pp., $5

This book is a summary of the methods used by fishery biologists to estimate the various parameters of population dynamics. The author has included many of the methods described in the literature in addition to republishing most of the material presented in his 1948 paper, "Methods of Estimating Vital Statistics of Fish Populations." In reviewing the literature the author did not include Japanese and Russian material, but a number of papers from these countries are listed in the bibliography.

The methods described are grouped by similarity of approach. The subjects treated include the estimation of survival and in some cases, population size from age composition, marking experiments, and catch statistics; the determination of the rate of growth, the relationship of stock size, recruitment and yield; and the relation of equilibrium yield to stock size and rate of fishing.

The description of most methods includes the presentation of formulae, a discussion of the basic conditions necessary for the method to yield valid estimates, and an example of its use. More detailed treatment is given in some cases but, in general, the development of formulae is not described. This results in little calculus being used in the text, so most of the text can be followed with a knowledge of algebra.

This text only describes the methods of estimating population parameters with the use of necessary measurements. It does not attempt to describe the techniques that must be used to get these necessary measurements. For example, tagging and marking procedures, determination of age, and creel checking techniques are not described.

This book certainly fulfills the need for having the many methods fishery biologists have used in estimating population parameters described in a logical sequence in one place. In doing this it was necessary to abbreviate the descriptions of many methods, and this may encourage the use of the book in a "cookbook" manner. However, when it is used properly, it will be extremely valuable, and everyone working with fish populations should have access to a copy.—*H. K. Chadwick, California Department of Fish and Game.*

Environmental Conservation

By Raymond F. Dasmann, Ph.D., John Wiley & Sons, Inc.; New York, N. Y., 307 pp., profusely illus. with black and white photographs and line drawings, $6.50

In the introduction to this beautifully bound and illustrated volume we find in two pages an excellent summary of the conservation problems facing the world. The author uses words as a hammer to set the stage for his coming discussion of mankind's survival. As an example, "Now the world is small, and people are many. Serious blunders made now can be irrevocable. Responsibility rests more heavily upon the shoulders of all of us. We have lost most of our margin of error." This sets the tone of the book. The author is concerned, and he wants the reader to be concerned. He states in his preface, " * * * it attempts to sketch the broad background of conservation, and to allow the instructor to fill in the details from local experience."

Dr. Dasmann makes it apparent that the conservationist is much more than a bird lover, a contour farmer, a politician or a game or fish manager. He has managed to point out magnificently that *people* are after all the real problem; that animals and land and water in themselves are only facades of the real problem; that man must face himself, decide what he wants, what he must have, before any specifics of land, game, or water management will take on meaning. He points out truly, that we in the United States for example have lost our frontier, yet " * * * retain

our frontier outlook. We still believe that more people means more hands to work and more customers to buy. We look forward to an ever-expanding business and industrial economy, often without critically examining the resource base that must support that economy." And further, "* * * it is difficult to forsake the philosophy of a young and growing nation. * * * America * * * is reaching the time when the transition must be made, when the sober responsibilities of maturity must be substituted in our natural philosophy for the dreams of youth."

The basis for this book may be summed up in two of the author's sentences. "Populations no longer starve in silence. Empires no longer die quietly."

In attempting a long view of this book this reviewer would say the chapters on resources as such are good. Chapter headings as "The Major Biotic Regions, Land and Wild Animal Life, Water and Fisheries, Forests and Man, Livestock on the Range, etc.," indicate that this will be a useful textbook to the beginning conservationist—be he wildlifer, rancher, or county agent. These chapters are well written, very much up-to-date, and full of the author's own experience and philosophy, especially in regard to wildlife management. "It is necessary to re-examine basic thinking about wildlife problems and enter a new era of wildlife conservation, of the conservation of balanced biotas in place of specialized concentration on increasing numbers of huntable game. It should be an era in which the needs of the people as a whole, for natural environments with abundant and varied animal life, are given precedence over the wants of the hunter."

The above is strong language. But, the challenge to the wildlife administrators of the State and Nation is clear, and the case is documented. "There is an increasing feeling also that wild land and wildlife may be strangely important for the preservation of man himself." This is not a new idea, but it bears repeating and sober consideration.

Some of the other chapters such as "Man's Record on the Earth, The Problem of Population, The Outlook, etc.," offer the instructor a matchless opportunity to expand the intellectual horizon of his students. Any reader will benefit from these more philosophical chapters.

As a final opinion this reviewer feels that lower division students will find this an excellent textbook of conservation principles and practice. More important however, will be the tremendous challenge Dr. Dasmann has presented to the users of the environment. Graduate students and professional conservationists will find much in this book. It will require thought on the part of the reader, and it will require familiarity with other books in this field and with publications in the related fields of sociology and economics. The very excellent up-to-date bibliographies at the end of each chapter are in themselves a challenge to one who is interested. Any individual who reads this book and the references will have a new and better understanding of man and "Environmental Conservation."—*Harold D. Bissell, Game Management Branch, California Department of Fish and Game, June, 1959*

The Conservation of Natural Resources

By Richard C. Haw; Faber and Faber, London, 1959; 256 pp. illustrated. 30 shillings

This book describes the problems of soil and water conservation of the dry tropical and subtropical countries. Although worldwide in scope, the author draws mainly from his experience on the African continent where he is instructor in soil and water conservation at the Dombashawa School in Southern Rhodesia.

He points out the fact that past civilizations have been wiped out by erosion and this process is continuing in some parts of the world today. The United States is classed as having already lost one-third of its topsoil while Africa has lost 30 percent of its soil productivity through the past century. We are also accused in this Country of losing 21 times as much plant food in the discharge of our rivers to the oceans annually as is removed by all agricultural crops.

His basic concept is that "soil really belongs to mankind. Those who work it have the responsibility of ensuring that it is conserved for future generations. It should be handed on in no worse condition than that in which is was received." A firm believer in the Malthusian concept, he classes control of world populations in relation to food production capacities as mankind's number one problem. This paragraph is worth repeating:

"At the present rate of world population growth, there will be 6,000 million people existing on but 4,000 million cultivable acres by the end of this century! An immediate increase in world food production of 25 percent is needed *now*—what of the future which demands increases of food production for 34 million extra mouths each year?

Whilst science can increase yields of crops, and make available new artificial or natural food sources, it seems pointless to produce more, merely to have it consumed by ever-increasing populations living on a subsistence level. The more food is produced, the more of these unfortunate millions will survive to make the dilemma even more pressing. Very little is being done to educate the masses on this, the world's greatest single problem."

On the optimistic side he does point out that properly managed land can go on yielding indefinitely. It is however, a slow, difficult and costly process to get the world's farmers to adopt scientific methods. As Jacks and Whyte in their book entitled "Rape of the Earth" express it: "Erosion will not stop until some economic trend definitely antagonistic to soil exploitation becomes manifest throughout the world."

In addition to these thought-provoking initial chapters, author Haw presents in the remainder of his book land and water management techniques which follow basic principles applicable anywhere in the world. This will be a valuable source book of information for both land and water management in Africa. There are many similar books more directly applicable to these problems as they pertain to the Western Hemisphere. It does, however, give one an insight into how worldwide and important the problems of soil and water conservation are.—*Willis A. Evans, California Department of Fish and Game.*

Marine Ecology

By Hillary B. Moore; John Wiley and Sons, Inc., New York, 1958; xi—493 pp.; illus. $10

"Marine Ecology" is intended primarily as a textbook for the classroom. If used as intended, it should, in conjunction with other publications of more specialized nature, serve quite well. The organization and presentation of material follow a logical and orderly sequence, easy to understand.

The first four chapters concern environmental factors (physical, chemical and biological) affecting marine ecology. From there one moves easily into habitats (two chapters) and organisms inhabiting and making up the various marine communities and life zones (four chapters). An appendix systematically lists the genera referred to in the text. Then there are 27 pages of references (over 540 entries) and a quite complete index.

As in any work of this sort, the magnitude of the field is too great for any one man to own a firsthand knowledge of all the intricate ramifications. This necessitated a considerable dependency upon the printed works of others. In sorting through these various "jewels" and later transcribing the selected information, some of the accuracy (there are numerous typographical errors) and meat has been inadvertently mislaid by the author.

No doubt every person concerned with ecology has a slightly different opinion of what is or is not important and what should or should not be incorporated into a text such as this. My own bone of contention lies in the author's failure to stress the importance of polution—a blight on and a threat to the continued healthy existence of natural communities along every seashore within reach of man's "modern" waste disposal systems.—*John E. Fitch, California Department of Fish and Game.*

We Come From the Sea

By Hans Hass; Doubleday and Company, Inc., Garden City, N.Y., 1959; 288 pp., black and white plates, 10 color plates, 3 maps. $6.50

This volume is 288 pages of rapidly moving travelogue, written in a style often associated with National Geographic Magazine. It carries the reader underwater from the Red Sea to the Great Barrier Reef, and from the Azores through the Caribbean Sea to the Galapagos and Cocos Islands in the eastern Pacific.

It is a tale of contrasts: from riding a 25-foot whale shark, unharmed, to almost losing a life to a 5-foot 4-inch brown shark; from observing the behavior of sharks to investigating the pressure exerted by a giant clam; from discussing myths and legends associated with the oceans to the more serious contemplation of current theories based on scientific knowledge.

The author takes the reader on a mental raft of words in quest of further understanding of the sea and its inhabitants. With the romance of a poet and the exactness of an historian, author Hass verbally paints vivid pictures of the sea that rival his excellent photographic record.

The author has taken underwater photographs throughout the oceans of the world. Among the more spectacular ones appearing in this book are scenes of the harpooning and capture of a sperm whale off the Azores and photographs of a whale shark. Those depicting the hammerhead and tiger shark are so sinister in appearance as to be spine chilling even to the least apprehensive reader.

Throughout the book, by word picture and photograph, the author stresses the kinship of man with the sea. He points out that man, now being slightly removed from the sea re-enters it with feelings of apprehension toward the unknown.

Of his discussions concerning the dangers of sharks, the author states "*** you must never feel too safe and *** it is very imprudent to dive anywhere if there is a smell of blood about. You must be prepared, always and everywhere for any sort of surprise." This statement was made after the author was forced to flee the water near Port Sudan by two sharks, one of them a white shark or man-eater.

Though adventure and colorful photography might be enough in most books, Hans Hass picks up threads of science and skillfully weaves them into his tapestry of the sea. A short dissertation on the origin and growth of coral reefs is added when talking of diving on the Great Barrier Reef. A thread or two of Darwin's concept of the Descent of Man and its broad implications are added when the Galapagos Islands are visited. Bits of fish psysiology and behavior in schooling and communication are mentioned in the chapter Fish Talk.

The final impression is one of a well-planned work, both artistic and intellectual, attempting to explain some of the phenomena of the watery world around us. One is given the thought that man should try to understand, not be struck dumb with awe, at his ancestral birthplace. Man, having risen from the ancient oceans, now returns in search of understanding of himself and his world.—*Charles H. Turner, California Department of Fish and Game.*

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STATE OF CALIFORNIA
FISH AND GAME COMMISSION

Notice is hereby given that the Fish and Game Commission shall meet on October 9, 1959, in the California State Building, First and Broadway, Los Angeles, California, to receive recommendations from its own officers and employees, from the department and other public agencies, from organizations of private citizens, and from any interested person as to what, if any, regulations should be made relating to fish, amphibia, and reptiles, or any species or subspecies thereof, in accordance with Sections 206-208 of the Fish and Game Code.

FISH AND GAME COMMISSION
WM. J. HARP
Assistant to the Commission

Notice is hereby given, in accordance with Section 206 of the Fish and Game Code, that the Fish and Game Commission shall meet on December 3, 1959, in the State Employment Building, 722 Capitol Avenue, Sacramento, California, to hear and consider any objections to its determinations or proposed regulations in relation to fish, amphibia, and reptiles, for the 1960 Angling Season, such determinations resulting from hearing held on October 9, 1959.

FISH AND GAME COMMISSION
WM. J. HARP
Assistant to the Commission